STATE OF ILLINOIS
HENRY HORNER, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION

DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*

REPORT OF INVESTIGATIONS—NO. 33

CONTRIBUTIONS TO THE STUDY OF COAL

Mineral Matter of No. 6 Bed Coal at West Frankfort, Franklin County, Illinois

BY

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MINERAL MATTER OF NO. 6 BED COAL AT WEST FRANKFORT, FRANKLIN COUNTY, ILLINOIS

By Clayton G. Ball[1]

CHAPTER I

SUMMARY

This report presents the results of a new procedure in ascertaining the amount and character of mineral matter in coal as applied to No. 6 bed coal at West Frankfort, Franklin County, Illinois. The separable mineral matter was isolated from finely crushed coal by float-and-sink separations, and was identified in detail by petrographic methods, while the mineral matter remaining in the coal after mineral separation was studied by means of chemical analyses. More than 95 per cent of the mineral matter is found to consist of but three minerals, calcite, pyrite, and kaolinite. The latter mineral occurs both in detrital clay and as a prominent filling in desiccation cracks and fusain cavities in the coal.

The amount of total mineral matter, the amounts of individual mineral components, and the relative abundance of each mineral component with respect to the others, vary from bench to bench in the coal bed. Certain mineral components are concentrated in certain benches, resulting in unequal distribution of the mineral impurities. A large part of the total thickness of the bed contains an amount of mineral matter considerably less than the average value. The composition of this mineral matter, moreover, is such that the coal ash softens at a high temperature. These considerations suggest a possibility of advantageous selective mining.

The mineral matter remaining in the coal after removal of the separable mineral matter, as determined by ash analyses, is closely similar to that of the removable constituents, both in composition and in quantity. A varying amount of silica in excess of the quantity required to combine with the available alumina to form kaolinite, however, is found in each bench of the coal bed. The occurrence and amount of such excess silica, and the reasons for retention of a considerable portion of the mineral matter within the coal after mineral separation, constitute important questions for further investigation.

Detailed knowledge of the actual mineral constitutents in coal is of particular value in determining the cause of variations in the behaviour of the ash during combustion and in the evaluation of formulae designed to convert coal ash values into mineral matter values, such values forming the approved basis of scientific classification of coal by rank.

[1] Assistant Geologist, Division of Petrography.

Introduction

The mineral matter present in coal and the ash residual from its combustion are not identical. Nevertheless, in estimating the amount and nature of impurity in coal, it is customary to regard the ash as the equivalent of the mineral impurities, and the ash analysis as the expression of the nature of these impurities. As a matter of fact, the analysis of the coal and of the ash provides but imperfect information concerning the actual nature of the original extraneous mineral impurities in the coal, the identity and quantity of which must be roughly estimated from the nature and quantity of the various oxides of inorganic elements discovered by analysis.

The exact nature of the extraneous minerals in coal can best be determined by the methods of microscopic petrology. These methods make possible the identification of the actual minerals, and thereby provide a substantial basis for the recalculation of mineral matter from the ash analysis in terms of the minerals actually known to be present. The correction of ash values to mineral matter values is a calculation of great importance in determining what are known as "pure coal" values, that is, the mineral matter-free values of coal.

The manner in which the inherent or organically combined mineral matter occurs in coal is not revealed by petrographic methods and still remains largely unknown. The amount of such material, however, is evidently very small as shown in the course of the discussion.

The presence of certain minerals, particularly pyrite and calcite, in coal is a matter of common knowledge, but little precise information is available concerning the amount or form of other minerals present. Petrographic investigation of the identity, characteristics, distribution, and abundance of mineral constituents in Illinois coals has accordingly been conducted by the Illinois State Geological Survey in order to provide fundamental information on the mineral matter in coal, and to contribute necessary data to stratigraphic, physical, microbotanical, and beneficiation investigations now in progress.

Before undertaking a petrographic study of this kind, it was necessary to develop a satisfactory method of mineral recovery. Having developed such a method of mineral separation, other and more fundamental objectives could be attained, such as the determination of the nature, mode of occurrence, distribution, and abundance of the mineral constituents and the interpretation of analyses of coal ash in terms of the original mineral impurities in the coal. The precise data assembled during the investigation will provide a basis for correct understanding of the possibilities and limitations attending selective mining and cleaning processes, and of variations in ash fusibility.

It is believed that the present report, based on the development of a suitable laboratory method for mineral separation and the detailed petrographic analysis of the mineral matter in a single section of a representative Illinois coal bed, is fully warranted both because of the importance of describing a new method of research into the fundamental composition of coal, and because of the distinct significance of the results.

The Field of This Investigation

The term *mineral* is here employed as defined by the mineralogist. The *mineral matter* of coal refers to the non-organic components of coal, varying in dimensions from discrete particles to disseminated grains of colloidal size. Since such material is only mechanically associated with the coal, the possibility of its separation is determined mainly by the size of the individual particles, material below a definite limit being inseparable from the coal partly because of its failure to sink in the separating liquids and partly because of its inclusion in the coal even when the latter is ground to pass the finest sieve employed. Inherent mineral matter, consisting of organically combined elements other than carbon, hydrogen, oxygen, and nitrogen, and of salts and oxides deposited in plant tissues during their growth, is not included in the field of this investigation. Terms synonymous with *mineral matter* are *mineral constituents, mineral components,* and *mineral impurities.*

The ash of coal is the residue that remains after complete incineration and contains material derived from both extraneous and inherent mineral matter. The nature of the ash produced by the separable mineral constituents provides a basis for determining the extent to which inherent mineral matter probably contributes to the total ash obtained from a coal.

In acordance with the present custom of the Illinois State Geological Survey[2], the terminology of coal description proposed by Stopes[3] is employed in referring to the banded ingredients of bituminous coal.

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[2] McCabe, L. C., The lithological and botanical constituents of coal No. 6 at Nashville, Illinois: Univ. of Illinois, unpublished Master's thesis, on file at Illinois State Geological Survey, Urbana, Illinois, 1933.
McCabe, L. C., Mitchell, D. R., and Cady, G. H., Banded Ingredients of No. 6 Coal and Their Heating Values as Related to Washability Characteristics: Illinois State Geol. Survey, Report of Investigations No. 34, 1934.

[3] Stopes, M. C., On the four visible ingredients in banded bituminous coal: Proc. Roy. Soc., London, Vol. 90B, 470, 1919.

FIG. 1.—Index map showing boundary of the Illinois coal field and location of the New Orient mine in Franklin County.

The Coal Chosen for Investigation

LOCATION

The coal research program that was inaugurated by the Illinois State Geological Survey in 1931 involves the study of a series of complete columnar sections of representative Illinois coals. These investigations include the use of polished and etched sections, thin sections, macerated products, chemical analyses, X-ray radiographs, and the methods of petrographic analysis, particularly as applied to mineral components. The first column of the series chosen for petrographic analysis was number 24, obtained in August, 1931, from the New Orient mine, located just north of the town of West Frankfort, Franklin County, Illinois, and operated by the Chicago, Wilmington and Franklin Coal Company. The main shaft of this mine is located in the SE.¼ SW.¼, sec. 13, T. 7 S., R. 2 E., (Fig. 1). The column was taken at a point 8000 feet north and 3500 feet west of the main hoisting shaft in room 1, 12th north entry, off the 10th west entry, off the main north entry.

The column as collected represented a thickness of 89.1 inches, but did not include 10.1 inches of top coal and 7.7 inches of bottom coal which were not accessible to the samplers in the room where the column was cut. These portions of the bed were collected later at a time (September, 1933) when the face originally sampled was inaccessible so that the top and bottom benches were sampled about 2400 feet southeast of the locality where the column was cut in 1931, in the 6th north entry, off the 8th west entry, off the main north entry.

DESCRIPTION

The coal bed worked at the New Orient mine is the Herrin (No. 6)[4] bed of the Illinois series. At the shaft of this mine the coal lies 479 feet below the surface and has an elevation of 80 feet below sea-level. Coal No. 6 is characterized throughout the southern part of Illinois by a benched structure and by a widespread one- to two-inch parting of blue-gray carbonaceous clay, locally pyritized, known as the "blue band", which generally occurs from one to two feet above the base of the bed. In the part of the New Orient mine from which the column was taken this band is 20 inches above the base and averages 1.6 inches in thickness.

According to R. Thiessen[5], coal No. 6 in the adjacent No. 1 mine of the same company is composed almost entirely of bright coal and is characterized in thin sections by its high anthraxylon (vitrain) content and

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[4] Cady, G. H., Coal Resources of District VI: Illinois State Geol. Survey Coal Mining Investigations Bull. 15, 1916.

[5] Thiessen, R., Carbonizing properties and constitution of No. 6 bed coal from West Frankfort, Franklin County, Illinois: U. S. Bureau of Mines, Technical Paper 524, 1932.

numerous occurrences of fusain as either small lenticles or thin partings. Numerous vertical cleats or fissures filled with mineral matter occur throughout the entire thickness of the bed. Although the blue band is the most conspicuous impurity within the coal bed, several thinner clay partings are present but are less constant in occurrence.

Acknowledgments

The author gratefully acknowledges his indebtedness to the following members of the staff of the Illinois State Geological Survey: Dr. M. M. Leighton, Chief, with whose permission the work was undertaken and the final results submitted in dissertation for the Doctorate at Harvard University; Dr. G. H. Cady, Senior Geologist and Head of the Coal Division, and Dr. R. E. Grim, Head of the Division of Petrography, who supervised the entire investigation as well as the preparation of the final report; Mr. L. C. McCabe, Assistant Geologist, who prepared the column for petrographic treatment, and who prepared the coal for photography and radiography; Dr. O. W. Rees, Associate Chemist, Analytical Division, under whose supervision the chemical analyses were prepared; and Dr. Gilbert Thiessen, Associate Chemist, who contributed many valuable suggestions.

This report was submitted in dissertation to the Division of Geological Sciences, Harvard University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The writer is particularly indebted to Prof. E. S. Larsen, Jr., Professor of Petrography, Harvard University, for his suggestions and general supervision throughout the preparation of the report.

The author takes pleasure in extending grateful acknowledgement to L. D. Smith, vice-president, and H. A. Treadwell, general superintendent, of the Chicago, Wilmington, and Franklin Coal Co., Chicago, Illinois, and to J. R. Foster, superintendent, Orient No. 2 mine, West Frankfort, Illinois, for their assistance and cooperation in conducting this study.

CHAPTER II—LABORATORY TECHNIQUE

Mineral Separation

Although space does not permit detailed descriptions of the experiments leading to the development of the laboratory technique employed in this investigation, this information has been placed on file in the offices of the Illinois State Geological Survey. Procedures similar to that recommended by Bird and Messmore[1] were tried out, but the necessity for rapid separation of a large number of small samples led to the use of separatory funnels for making float-and-sink separations. A detailed description of this method follows.

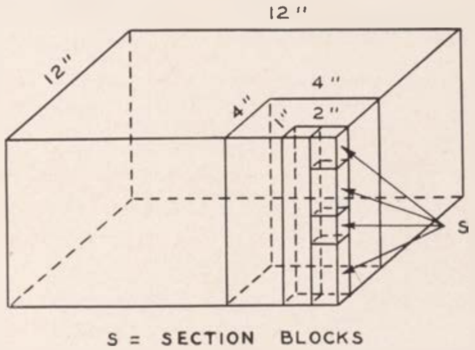

Fig. 2.—Diagram showing division of coal column into section blocks.

From the original column sample, consecutive blocks measuring 4 by 4 inches at the base were cut from each bench for the paleobotanical and lithologic investigations now in progress by the Coal Division of the Illinois State Geological Survey. Smaller blocks measuring 1 by 2 inches at the base were then prepared for mechanical separation and petrographic analysis, one-half being put aside for chemical study and reserve.

The selected block, measuring 1 by 1 inch at the base and representing a bench of the coal bed, was in some cases subdivided into two or more smaller units of varying height. Division was made along bedding planes, each unit representing as homogeneous a section of the coal bed as possible.

[1] Bird, B. M., and Messmore, H. E., The float-and-sink testing of fine-sized coal: Univ. of Washington Eng. Exp. Sta., Bull. 46, 1928.

TABLE 1. *Number and height of section blocks cut from column 24*

Bench No.	Thickness mm.	Block No.	Thickness mm.	Height above base mm.
R3	59.0			2714.5
R2	90.5			2655.5
R1	108.0			2565.0
11B	112.5			2457.0
		11A–4	22.0	
		11A–3	21.0	
		11A–2	24.0	
		11A–1	21.0	
11A	88.0			2344.5
		10–3	20.5	
		10–2	34.0	
		10–1	36.5	
10	91.0			2256.5
		9–5	29.0	
		9–4	30.0	
		9–3	22.0	
		9–2	21.5	
		9–1	17.0	
9	119.5			2165.0
8B	146.0			2046.0
8A	59.0			1900.0
		7C–5	29.5	
		7C–4	48.0	
		7C–3	35.0	
		7C–2	33.5	
		7C–1	17.0	
7C	163.0			1841.0
		7B–5	39.0	
		7B–4	28.0	
		7B–3	29.0	
		7B–2	30.0	
		7B–1	29.0	
7B	155.0			1678.0
		7A–4	22.5	
		7A–3	26.0	
		7A–2	21.5	
		7A–1	27.0	
7A	97.0			1523.0
		6–2	54.5	
		6–1	48.0	
6	102.5			1426.0

TABLE 1—(continued)

Bench No.	Thickness mm.	Block No.	Thickness mm.	Height above base mm.
5	142.5			1323.5
		4D–6	18.0	
		4D–5	21.5	
		4D–4	19.0	
		4D–3	19.0	
		4D–2	18.0	
		4D–1	16.0	
4D	111.5			1181.0
		4C–5	25.0	
		4C–4	18.0	
		4C–3	23.0	
		4C–2	16.5	
		4C–1	21.5	
4C	104.0			1069.5
		4B–5	18.0	
		4B–4	17.5	
		4B–3	20.0	
		4B–2	18.0	
		4B–1	25.5	
4B	99.0			965.5
		4A–4	25.0	
		4A–3	24.5	
		4A–2	18.5	
		4A–1	25.0	
4A	93.0			866.5
		3B–6	14.0	
		3B–5	17.5	
		3B–4	22.5	
		3B–3	25.0	
		3B–2	26.5	
		3B–1	21.0	
3B	126.5			773.5
		3A–7	20.5	
		3A–6	22.0	
		3A–5	19.5	
		3A–4	20.0	
		3A–3	25.0	
3A	100.5			647.0
		3A–2	20.0	
		3A–1	20.0	
BB	40.0			546.5

TABLE 1—(continued)

Bench No.	Thickness mm.	Block No.	Thickness mm.	Height above base mm.
		2–5	35.0	
		2–4	18.0	
		2–3	17.0	
		2–2	20.5	
		2–1	19.5	
2	110.0			506.5
1B	117.0			396.5
		1A–4	19.0	
		1A–3	21.0	
		1A–2	23.0	
		1A–1	22.0	
1A	85.0			279.5
F2	105.5			194.5
F1	89.0			89.0
Total........	2714.5			

The entire process of selection is indicated in figure 2. Homogeneity was determined by study of photographs of the polished surfaces and radiographs of similar blocks previously prepared by L. C. McCabe of the Coal Division. For column 24, 80 unit blocks (hereafter designated as section blocks) were prepared, varying from 1.4 to 14.6 centimeters in thickness, as indicated in Table 1.

Each section block was separately crushed in a Braun crusher with its grinding plates set approximately ⅛ inch apart. Any closer setting of the plates tended to fracture the coal to such small sizes that separation of mineral matter was difficult, whereas at ⅛ inch most of the resulting crushed grains were larger than 100-mesh. Tyler Standard screens were used (Table 2).

After the preliminary crushing the fraction resting on the 48-mesh screen was re-ground in a small cone mill crusher so that it all passed through 48-mesh. The entire sample was then screened, using a Ro-Tap machine for from 8 to 10 minutes, to three grade sizes, namely (1) through 48, on 100-mesh; (2) through 100, on 200-mesh; and (3) through 200-mesh. The weight of each of the three fractions was determined to a milligram, their sum representing the total weight of the section block.

TABLE 2. *Tyler Standard Screens—mesh sizes*

Mesh	Size of opening	
	Inch	Millimeter
48	.0116	.295
100	.0058	.147
200	.0029	.074

FIG. 3.—Laboratory equipment for float-and-sink separation.

The mineral separations were carried on in large glass separatory funnels measuring 8 inches in height, 3½ inches across the mouth, and tapering regularly from the mouth to a valve controlling the ⅛-inch outlet (Fig. 3). Carbon tetrachloride and bromoform were mixed in the proportions necessary to produce a liquid having a specific gravity of 1.70, this having been determined to be the most satisfactory. Each of the three screen size fractions was slowly poured into a funnel one-half filled with the heavy liquid, after which the finely crushed coal was thoroughly wetted and immersed by adding liquid from a wash bottle or small beaker. During the period of separation, which required about one hour for the 48 × 100-mesh fraction, four hours for the 100 × 200-mesh fraction, and sixteen hours for the 200-mesh × 0 fraction, the ingredients in the funnels were occasionally re-agitated by the addition of small amounts of heavy liquid.

After complete separation the float-and-sink fractions were collected on suitable filter papers, thoroughly washed with acetone, and allowed to dry at room temperature. The heavy liquid could be used for additional separations until its specific gravity became altered by evaporation or until the bromoform became discoloured through exposure. The acetone and heavy liquid mixture obtained from the washing was put aside for subsequent recovery of the bromoform. The heavy fractions, representing the total separable mineral matter, were weighed after thorough drying and were put aside for separation into their individual mineral constituents.

Since it seemed probable that some of the fine removable matter might still be bound up in the two larger light fractions after separation, these portions were combined and re-ground in the cone mill to minus 200-mesh and subjected to a second separation.

The procedure described provided four heavy separates for each section block; namely, 48 × 100-mesh, 100 × 200-mesh, and a 200-mesh × 0 heavy fraction from the first separation, with an additional 200-mesh × 0 fraction from the second separation. It also provided two light fractions, one 200-mesh × 0 light fraction from the first separation, and one 200-mesh × 0 light fraction from the second separation. The total amount of mineral matter separable by the method described was contained in the four heavy fractions. The light fractions were reserved for chemical determinations of the quantity and character of their ash. The quantity of ash present in the coal from which the mineral matter had been removed, and the theoretical ash obtained from the recovered minerals, represents the total ash content of the coal.

Separation of Individual Mineral Constituents

After determining the amount of mineral matter obtained in the second separation, the heavy fractions, which contained the separable mineral matter, were combined to produce three size fractions: namely, 48 × 100-mesh, 100 × 200-mesh, and 200-mesh × 0. Each of these mesh sizes was digested in cold dilute hydrochloric acid for from one-half hour or less to one hour, depending upon the amount of soluble material present. The insoluble residues were weighed to determine the amount of soluble material removed and were then separated into two fractions by float-and-sink methods using bromoform with a specific gravity of 2.85. Each fraction after thorough washing with acetone was dried, weighed, and put aside for microscopic study.

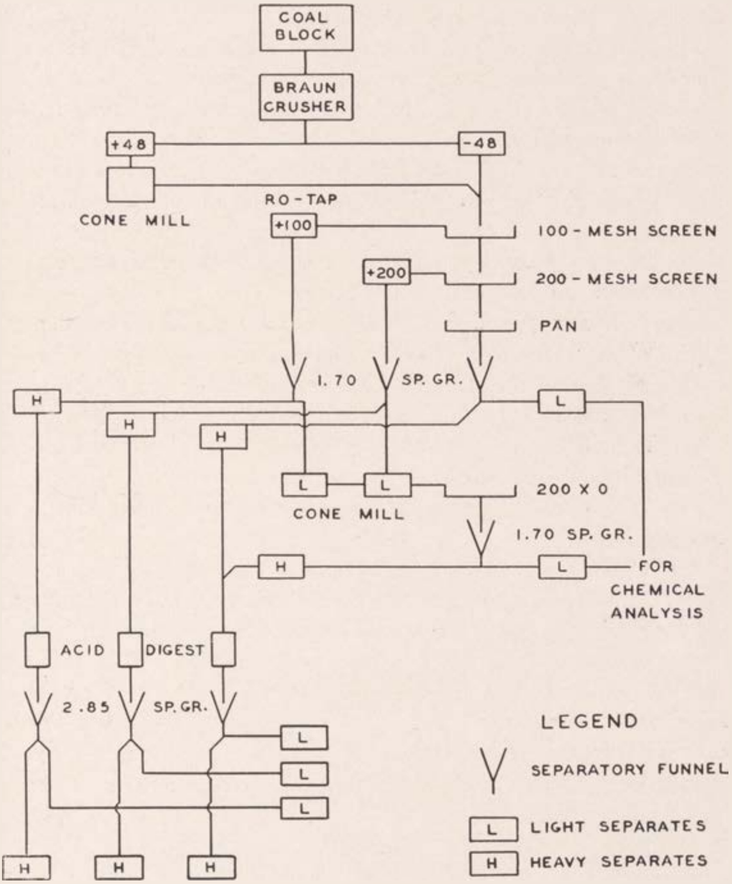

FIG. 4.—Flow sheet showing method of mechanical separation of mineral constituents.

Summary of Laboratory Procedure

As described above, the method of separating mineral constituents from the coal consisted of the following steps (Fig. 4):

1) Selection and splitting of section blocks from the column.

2) Grinding with Braun crusher and re-grinding with cone mill so that entire sample passed through the 48-mesh screen.

3) Sieving on Ro-Tap machine to screen sizes (a) through 48, on 100-mesh; (b) through 100, on 200-mesh; and (c) through 200-mesh.

4) Separation of total mineral matter from each screen size by float-and-sink operations at 1.70 specific gravity.

5) Re-grinding of float fractions of sizes (a) and (b) to through 200-mesh.

6) Separation of mineral matter of these re-crushed float fractions at 1.70 specific gravity.

7) Combining of all heavy fractions of similar size.

8) Determination of acid-soluble portion of the mineral constituents from the three screen sizes.

9) Separation of light and heavy acid-insoluble mineral matter of each screen size at 2.85 specific gravity.

This procedure provided the following quantitative information:

1) Weight of section block examined.

2) Weight of total separable mineral matter.

3) Weight of acid-soluble portion of mineral matter.

4) Weight of acid-insoluble mineral matter heavier than 2.85 specific gravity.

5) Weight of acid-insoluble mineral matter lighter than 2.85 specific gravity.

It has been indicated that the mineral matter removed by the above laboratory procedure represents the "total" separable mineral matter. It is not supposed that this is a standard quantitative measurement by which the mineral content of different coals may be compared, since refinement of this procedure or some different method of separation might very conceivably result in a greater yield of separable mineral matter. In this report, however, references to separable and non-separable mineral matter in column 24 are based on the described method of mineral separation.

CHAPTER III—CHARACTER AND COMPOSITION OF SEPARABLE MINERAL CONSTITUENTS

The petrographic study of the mineral constituents consisted first of a determination of their character and composition, and second, of a determination of their abundance and distribution. In this chapter the character and composition of the separated mineral impurities are considered.

The mineral impurities capable of separation from the coal by the laboratory processes described in the preceding chapter are found to consist of two different types. In one group occur the detrital minerals which were washed, blown, or otherwise transported into the coal basin during the time of peat accumulation. The second group includes mineral matter deposited in the interstices of the coal bed at some period after the initial accumulation of the peat had been completed.

Petrographic Procedure

The light and the heavy mineral separates remaining after acid digestion (p. 18) were subjected to independent petrographic examination. It was soon evident that the bulk of the mineral matter consisted of detrital clay and kaolinite in the light fraction and of pyrite in the heavy fraction, although both fractions always contained minor amounts of non-clay detrital minerals. Although the amount of this detrital mineral matter, excepting clay, was small, the characteristics, amount, and the nature of the distribution of these minerals in the coal bed were of interest.

The detrital grains in the two larger screen sizes, 48 × 100-mesh and 100 × 200-mesh, were readily distinguishable from the bulk minerals by their characteristic appearance under reflected and transmitted light and were identified by oil-immersion methods. The entire fractions of the 200-mesh × 0 size were mounted, when possible, on a single object slide for the identification of the detrital grains. A liquid of 1.60 refractive index was found to be suitable for identification of many of the mineral species.

Precise identification of many of the mineral varieties below 1/32 millimeter in diameter was rarely possible. Most of the material of and below this size, however, seemed to consist of detached grains and fragments of the detrital clay which normally occurred in aggregate form.

The physical appearance and characteristics of the bulk minerals in each size fraction were carefully studied. In the case of kaolinite petrographic identification was verified by chemical analysis, an X-ray diffraction pattern, and dehydration data.

Detrital Mineral Constituents

The detrital mineral matter in the coal seam consists mainly of clay occurring as horizontal partings or bands in the coal, or disseminated through its attrital layers. Other detrital particles are present in nearly every section block, and consist of minerals commonly occurring in the sandstones,[1], shales, and clays[2] associated with the coal. In the approximate order of their relative abundance in the coal column studied, these minerals are: quartz, feldspar, garnet, common hornblende, apatite, zircon, muscovite, epidote, biotite, augite, kyanite, rutile, staurolite, topaz, tourmaline, and chloritic material.

The non-clay detrital minerals, although always present, are quantitatively of little importance, invariably constituting less than one per cent of the total separable mineral matter or less than one-tenth of one per cent of the coal.

The *detrital clay* was not subjected to specific petrographic examination. Concurrent petrographic examination of the roof shales and noncalcareous underclays associated with Illinois coals has shown[3] that the finest material of the shales is a sericite-like mineral belonging to the potash-bearing group of clay minerals, and that the noncalcareous underclays are composed predominantly of kaolinite with varying mixtures of the sericite-like mineral. Since the clay partings in coal closely resemble underclay in physical character and structure,[4] it is considered probable that the minerals of the clay partings are similar to those of the underclays, or predominantly kaolinite.

Quartz, which is the most abundant mineral in the non-clay detrital group, occurs in all three screen sizes but is generally most abundant in the 200-mesh × 0 portion (less than 1/16 millimeter.) These smaller grains are angular to slightly rounded; the larger grains, especially in the 48 × 100-mesh (¼ to ⅛ millimeter) size are often moderately rounded. Extinction rarely shows evidences of strain, nor are inclusions noteworthy.

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[1] MacVeigh, E. L., Mineralogic studies of some Pennsylvanian sandstones: Univ. of Illinois, unpublished Master's thesis, 1932.

[2] Grim, R. E., Petrology of the Pennsylvanian shales and non-calcareous underclays associated with Illinois coals: Bull. Amer. Ceramic Soc., in press, 1935.

[3] Grim, R. E., Op. cit.

[4] Allen, V. T., Petrogrophic mineralogical study of the underclays of Illinois coal: Amer. Ceramic Soc., Jour., 15 (10), Oct. 1932, 571.

In a very few of the section blocks, notably in section 5 of block 2 and in section 2 of block 4D, small perfectly formed prisms of quartz are observed. These may have been transported into the coal in some protecting matrix which was later removed or they may have been formed in place. Secondary deposition of quartz upon any original detrital material was not observed.

Feldspar, although common, is not as abundant as quartz. Albite and orthoclase are the two types commonly observed, with microcline occasionally present. The grains are generally angular with clear-cut cleavage fragments sometimes apparent. In general the feldspars show little or no alteration.

Garnet is a common constituent occurring largely as the colorless to pale pink *grossularite.* Although in general these grains, in common with most of the detrital minerals, were less than ⅛ millimeter in cross-section, several fragments were observed as large as ¾ millimeter in their largest dimension.

Common hornblende of the green variety occurs in fairly well defined, unaltered cleavage fragments. Most of the grains show faint pleochroism.

Other minerals present in this group are apatite, muscovite, zircon, epidote, biotite, augite, kyanite, rutile, staurolite, topaz, tourmaline, and chloritic material. Zircon and apatite are more abundant than the others, although the total quantity of these minerals is very low. In general these minerals are angular to slightly rounded with little or no apparent alteration and are almost invariably less than ⅛ millimeter in diameter, usually less than 1/16 millimeter.

Minerals Deposited After the Formation of the Peat

KAOLINITE

Since the occurrence of kaolinite in coal is not well known and has not been described in detail, it appeared desirable to prepare a full account of its occurrence and physical character and the data on which its identification was based. The following section of this report has furnished the substance of a short article dealing with the presence of kaolinite in Illinois coal.[5]

In coal No. 6 in Franklin County, kaolinite occurs both in the vertical desiccation cracks in vitrain bands and in the cavities in bands and lenses of fusain. In other coals, for example the Grape Creek bed near Danville, Illinois, it has also been observed in the more conspicuous cleat joints extending through various thicknesses of the bed.

Desiccation, or checking, cracks in Illinois coals are commonly restricted to bands of vitrain, although where several of these occur close

[5] Ball, C. G., Kaolinite in Illinois Coal: Economic Geology, Dec., 1934, Vol. 29, 767-776.

together the cracks may break across the intervening clarain. Vertical dimensions of these cracks vary according to the thickness of the vitrain bands, ranging from less than a millimeter to rarely more than two centimeters. In width the cracks range from 0.05 to more than 1.0 millimeter with an average width of less than 0.5 millimeter. In horizontal section the cracks commonly form a rough pattern developed by two intersecting systems of fracture, one usually better developed than the other. The lines of desiccation may be less than one centimeter or as much as four or five centimeters apart, dividing the vitrain bands into square or diamond shaped blocks.

The kaolinite in the desiccation cracks appears opaque, white in color, with porcellaneous lustre. Under the microscope it is found to be entirely crystalline, although outward crystal form is not apparent. The crystals are commonly elongated, with their longest axis transverse to the margin of a veinlet, but usually extend only part way towards the center, the interior part being filled with unoriented grains. Diameters of the unoriented grains vary from .001 to .020 millimeter, while the average cross-section of the oriented grains is .005 millimeter.

Kaolinite may entirely fill a desiccation crack but it is more commonly associated with calcite, the latter mineral occurring as a thin film on one or both sides of the kaolinite. In certain parts of No. 6 bed, particularly below the blue band, calcite is the prominent mineral constituent in the desiccation cracks with kaolinite occupying a minor role. For the entire bed, however, the average content of kaolinite is considerably greater than that of calcite. If associated with even minor amounts of calcite, the kaolinite may appear to effervesce, a fact which has hitherto doubtlessly contributed to the confusion in its identification.

In a few parts of the bed, initial filling of a desiccation crack with kaolinite or calcite has evidently been followed by renewed desiccation, since two, or even three, distinct veinlets of the mineral may occur side by side in a single crack.

Kaolinite, as has been stated, occurs also in what were originally cellular spaces in fusain, or mineral charcoal. Fusain is an important lithologic ingredient of Illinois coals, occurring as widespread thin bands, as lenticles, and as individual particles, and appears to be the only banded ingredient of coal that possesses porous structure after coalification. Kaolinite in the pore spaces of fusain assumes the shape of the cavities which, when the containing walls are broken away, appear as very narrow, elongated cylinders. The cavity fillings are too small to be visible without magnification, the average diameter being less than 0.1 millimeter. Cylinders of kaolinite are occasionally found in what have been interpreted as resin rodlets, such cylinders having diameters from two to five times that of the cylinders in fusain. The average diameter of the individual grains composing the cylinders in fusain and resin rods is less than .010 millimeter.

Identification of the kaolinite is based on its optical properties, chemical analysis, dehydration curve, and X-ray diffraction pattern.

Optical properties.—Indices of refraction and birefringence of eight samples of kaolinite taken from various levels in the coal bed are listed in Table 3. Other optical constants could not be measured because of the small size of the constituent grains. Analogous optical constants for two type kaolinites representing the range of optical constants in the kaolinite group as given by Ross and Kerr[6] are included in the table.

TABLE 3. *Refractive indices of kaolinite*

Sources of kaolinite	α	γ	$\gamma - \alpha$
Coal No. 6, Franklin Co., Ill.			
(Height above floor)			
256.5 cm	1.560	1.565	.005
230.2 cm	1.560	1.565	.005
172.9 cm	1.560	1.566	.006
102.7 cm	1.561	1.565	.004
98.7 cm	1.560	1.565	.005
56.5 cm	1.560	1.566	.006
26.1 cm	1.560	1.565	.005
21.7 cm	1.560	1.564	.004
Near Pontiac, S. C. (A)	1.553	1.560	.007
Saline County, Ark. (B)	1.562	1.568	.006

A. Sand Hill Station, near Pontiac, S. C.
Ross and Kerr, U. S. Geological Survey Professional Paper 165-E, 1931, p. 162.

B. Globe bauxite mine, near Bauxite, Saline County, Ark.
Ross and Kerr, U. S. Geological Survey Professional Paper 165-E, 1931, p. 162.

Chemical analysis.—A small sample of the kaolinite was picked from the coal by hand for determination of its chemical composition and for dehydration data. Only clean white fragments were chosen for analysis. The analyzed kaolinite is compared with the two type kaolinites having the highest and lowest silica-alumina ratio as given by Ross and Kerr[7] and

[6] Ross, C. S. and Kerr, P. F., The kaolin minerals: U. S. Geol. Survey Prof. Paper 165-E, 1931, 162.

[7] Ross, C. S. and Kerr, P. F., Op. cit., 163.

with the theoretical composition of pure kaolinite of the formula $2H_2O.Al_2O_3.2SiO_2$ in Table 4. The chemical composition of the kaolinite in coal is found to agree with that of the kaolinite group, although loss on ignition is slightly higher than in any of the analyses heretofore published. This may be due to inclusion of small amounts of organic matter in the hand-picked sample.

TABLE 4. *Chemical analyses of kaolinite*

	1	2	3	4
SiO_2	43.80	43.78	45.56	46.60
Al_2O_3	39.36	40.06	37.65	39.49
Fe_2O_3	.82	.64	1.35	......
MgO	.16	.16	.07	
CaO	1.17	.36	.10	......
Loss on ignition	15.40	15.10	14.42	13.91
	100.71	100.10	[a]100.61	100.00
$SiO_2:Al_2O_3$	188:100	185:100	202:100	200:100

1. Kaolinite from Illinois coal. Analyses made under the supervision of Illinois State Geological Survey.
2. Kaolinite in vermicular grains from kaolin seams in bauxite, Saline County, Ark. F. A. Gonyer, analyst, U. S. Geological Survey Professional Paper 165-E, 1931, p. 163.
3. Kaolinite from Sand Hill station, near Pontiac, S. C. F. A. Gonyer, analyst, U. S. Geological Survey Professional Paper 165-E, 1931, p. 163.
4. Theoretical composition of kaolinite with formula $2H_2O.Al_2O_3.2SiO_2$.

[a] Includes traces of K_2O, Na_2O, and TiO_2.

Dehydration curve.—The amount of water loss at temperature intervals from 110° to 1000° Centigrade is given in Table 5. Loss of water (vertical coordinate) is plotted against temperature (horizontal coordinate) to give the dehydration curve shown in figure 5. The behaviour

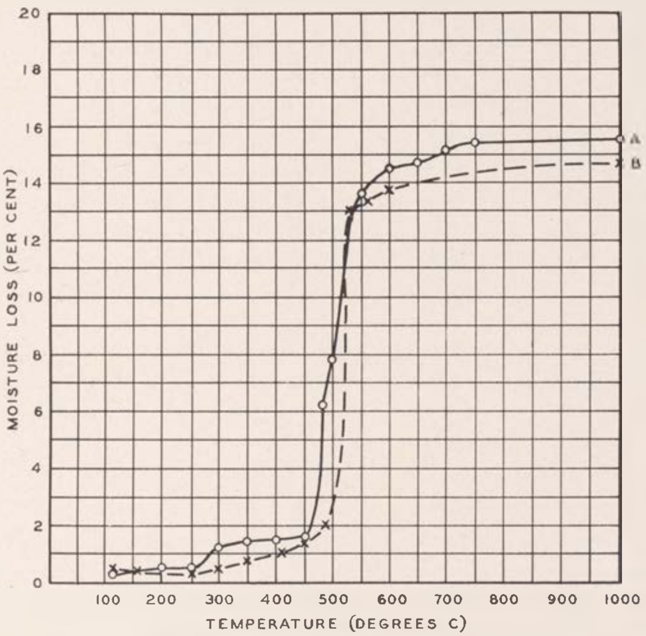

FIG. 5.—Dehydration curve of kaolinite. *A*, kaolinite from Illinois coal; *B*, Kaolinite from Pontiac, S. C.

of this mineral upon dehydration is similar to that of type kaolinites, as shown by Ross and Kerr[8]. The shape of the dehydration curve of the clay mineral in coal is sufficiently similar to curves of type kaolinites and sufficiently different from the distinctive curves of other clay minerals to justify its identification as kaolinite.

[8] Ross, C. S. and Kerr, P. F., Op. cit., 166.

TABLE 5. *Dehydration of kaolinite*

Temperature degrees C.	Moisture loss per cent	
	A	B
110	.26	.30
160	.....	.42
200	.55	.....
250	.54	.42
300	1.21	.51
350	1.47	.78
400	1.59	.....
410	.....	1.05
450	1.60	1.50
485	6.18	1.98
500	7.91	.....
525	.....	12.93
550	13.61	.....
560	.....	13.38
600	14.47	13.71
650	14.77	.....
700	15.12	.....
750	15.40	.....
950 to 1000	15.40	14.73

A. Kaolinite from Illinois Coal. Analyses made under the supervision of Dr. O. W. Rees, Illinois State Geological Survey.

B. Kaolinite from Pontiac, S. C. Ross and Kerr, U. S. Geological Survey, Professional Paper 165-E, 1931, p. 166.

X-ray diffraction pattern.—A small amount of the handpicked material was sent to P. F. Kerr for analysis by X-ray diffraction pattern. His comments on the results are as follows:[9]

> "Illinois clay No. 300. The sample submitted was very small and hardly large enough to allow an X-ray diffraction pattern of satisfactory intensity. Although the pattern is weak, the lines present agree with those of kaolinite."

Although the criteria obtained by any one method of examination would hardly justify positive identification of this clay mineral in coal as kaolinite, the accordant results of optical determinations, chemical analysis, dehydration curve, and X-ray diffraction pattern are conclusive proof of its identity.

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[9] Kerr, P. F., Report on X-ray studies of 100 selected samples of Illinois clays: Illinois State Geol. Survey, unpublished ms., 1933.

CALCITE

A number of mineral separates were examined microscopically before acid digestion (p. 18) in order to identify the mineral or minerals capable of removal by the acid treatment. The only acid-soluble mineral of frequent occurrence was found to be calcite. Since the acid employed during the treatment was cold and dilute (10 per cent), it is believed that the material removed by acid digestion consisted almost exclusively of calcite.

Most of the details descriptive of the occurrence of kaolinite are also applicable to the occurrence of calcite. This mineral occupies desiccation cracks, fusain cavities, and resin rodlet cavities. It is also the principal mineral constituent occupying the larger cleat cracks and joints in many Illinois coals. Under the microscope calcite usually appears as very thin, flat, angular cleavage fragments, and may be further distinguished from kaolinite by its transparency and characteristic cleavage.

PYRITE

The general modes of occurrence of pyrite in coal are more widely varied than those of any other mineral constituent.[10] It may occur as horizontal layers in the coal bed; as fillings in the vertical cleat cracks or joints; as nodular masses parallel with or at an angle to the bedding; as fillings in the desiccation cracks, the fusain and resin rodlet cavities more commonly occupied by calcite and kaolinite; as minute aggregates scattered irregularly through the various lithologic ingredients of the coal, especially within vitrain bands; and as intimate mixtures with and impregnations of certain parts of the coal such as the fusain walls.

In column 24 the occurrence of pyrite is in general restricted to fillings of desiccation cracks, fusain cavities, and resin rodlet cavities, and to minute aggregates scattered irregularly throughout the coal. Its more massive varieties are composed of moderately small crystals, often exhibiting crystal form. The disseminated aggregates are probably similarly composed of very minute crystals, commonly less than .001 millimeter in size, too small for determination of their crystal form.

Iron sulfides in coal have by general usage been long considered as pyrite. Newhouse,[11] however, has identified the iron sulfide found forming bands and lenses along stratification planes in many coal beds as marcasite, and it is possible that a considerable proportion of the iron sulfides in coal is marcasite.

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[10] Yancey, H. F. and Fraser, T., The distribution of the forms of sulphur in the coal bed: Univ. of Illinois Eng. Exp. Sta. Bull. 125, 1921.

[11] Newhouse, W. H., Some forms of iron sulphide occurring in coal and other sedimentary rocks: Jour. Geol. 35, 1927, 72-83.

Quantitative Differentiation Between Kaolinite and Detrital Clay

The precipitated kaolinite observed in desiccation cracks and fusain cavities is readily distinguished by its crystalline appearance from the detrital clay, even when finely ground. Since these two constituents possess approximately the same specific gravity, separation by gravity methods could not readily be accomplished, nor was any other method of quantitative separation devised. It became necessary, therefore, to rely upon visual estimations of the proportions of each constituent as a basis for determining their weights, these being added to the summary (p. 20).

CHAPTER IV—ABUNDANCE AND DISTRIBUTION OF SEPARABLE MINERAL CONSTITUENTS

Introduction

Determination of the abundance and distribution of the separable mineral constituents is based on the values listed on page 20 for the more important mineral components. Petrographic examination makes possible the following additional discriminations:

5a) Acid-insoluble mineral matter lighter than 2.85 specific gravity identified as detrital clay, composed of three screen sizes.

5b) Acid-insoluble mineral matter lighter than 2.85 specific gravity identified as kaolinite, composed of three screen sizes.

Quantitative measurements are provided for each of the four separable minerals with certain unimportant sources of error. Both the heavy and the light fractions remaining after acid digestion contain detrital grains other than clay, and all fractions may contain organic matter. It has been shown (p. 22) that the relative abundance of the detrital minerals other than clay is small, invariably less than one per cent of the total separable mineral matter. Their presence is therefore quantitatively disregarded in these studies; the heavy fraction is considered as being composed entirely of pyrite, the light fraction as detrital clay and kaolinite. Concerning the possible disturbing quantitative effect of the unavoidable association of some carbonaceous matter with these minerals, the following statements may be made.

ORGANIC MATTER IN THE MINERAL SEPARATES

Microscopic examination of the heavy fractions indicates that calcite and kaolinite are generally cleanly broken from the coal during fine crushing, except when in the form of fusain cavity fillings, in which cases the organic walls of the fusain are commonly brought down with the sink material. Fragments of the well-defined clay partings and of the more massive occurrences of pyrite are generally free from organic matter, but the clay present in attrital layers of the coal and the disseminated aggregates of pyrite often carried carbonaceous matter into the heavy separates.

Separation of mineral matter at 1.70 specific gravity is possible even though 90 per cent coal (specific gravity of 1.35) may be attached to pyrite (4.85 specific gravity), 74 per cent to calcite (2.72 specific gravity), and

72 per cent to detrital clay or kaolinite (2.6 specific gravity). The presence of considerable carbonaceous matter in the mineral separates is therefore possible. Under the microscope, however, it was observed that pyrite and detrital clay were usually free from carbonaceous matter when either made up 20 per cent or more of the separated mineral matter. Either detrital clay or pyrite, in other words, when composing more than one-fifth the total mineral matter in any section block, seem to occur in concentrated form rather than in disseminated aggregates. When either of these minerals composed less than 20 per cent of the separable mineral matter, however, they were likely to be associated with carbonaceous matter, although the weight of such mineral matter (less than one-fifth the total mineral matter) and consequently the weight of any attached organic material would be relatively unimportant.

Deposits of calcite and kaolinite in fusain are generally accompanied by varying proportions of organic matter, depending on the diameters of the openings and the thickness of the cavity walls. In order to ascertain the amount of organic matter actually present in an occurrence of this kind, two samples of kaolinite-filled fusain were ashed at approximately 600° C. for ten minutes. The results of the tests are shown in Table 6.

TABLE 6. *Organic matter in kaolinite-filled fusain*

Location of sample	1 *Gram*	2 *Gram*	3 *Gram*	4 *Gram*	5 *Per cent*
24–F1	.688	.552	.629	.059	8.57
24–1B	.689	.575	.655	.034	4.93

Column
1. Weight of kaolinite-filled fusain.
2. Weight after ashing.
3. Weight corrected for loss of water of hydration.
4. Weight of organic loss. (Column 1 minus column 3).
5. Proportion of organic matter to original sample.

This table indicates that even in such samples as would appear to contain a high proportion of organic matter, the actual proportion of the organic matter by weight is less than 10 per cent. In general it appears that organic matter, though usually present, is not of great significance to the weights and consequent proportions of the separated mineral constituents.

Abundance of Mineral Matter

The quantitative data for the total separable mineral matter and each of the four important constituent minerals are given in the Appendix. Of the 26 benches into which column 24 was divided by natural partings, 10 were treated as single section blocks, while the remaining 16 were further divided into 70 section blocks (Table 1, p. 14). Quantitative data are available for all of the 80 section blocks but for convenience in presentation were combined into the 26 blocks representing the natural benches. Since each block was necessarily exposed to moisture loss during its crushing and separation it is probable that the coal was essentially in an "air-dried" condition, the amount of moisture being about 4 per cent. The quantitative data throughout this report are based on the "air-dried" coal as weighed.

The tabulations of data (see Appendix) present the following information for each bench: (1) Weight before mineral separation, (2) weight and amount of the total separable mineral matter, and (3) weight and amount of each of the four mineral constituents.

Distribution of Mineral Matter

DISTRIBUTION BY SCREEN SIZE

Distribution of total mineral matter by screen sizes, presented graphically in figure 6 and in summary in Table 7, demonstrates the relative im-

Table 7. *Summary of distribution by screen size*

Mesh size	1 *Per cent*	2 *Per cent*	3 *Per cent*	4 *Per cent*
48 × 100	35.51	78.29	36.68	49.37
100 × 200	23.11	44.07	21.63	30.23
200 × 0	41.38	23.91	00.06	18.81
200 × 0 (recrushed)	.....	10.53	00.02	1.59

Column
1. Proportion of blue band mineral matter in each screen size.
2. Maximum proportion of mineral matter in each screen size for any one block.
3. Minimum proportion of mineral matter in each screen size for any one block.
4. Average proportion of mineral matter in each screen size for all blocks.

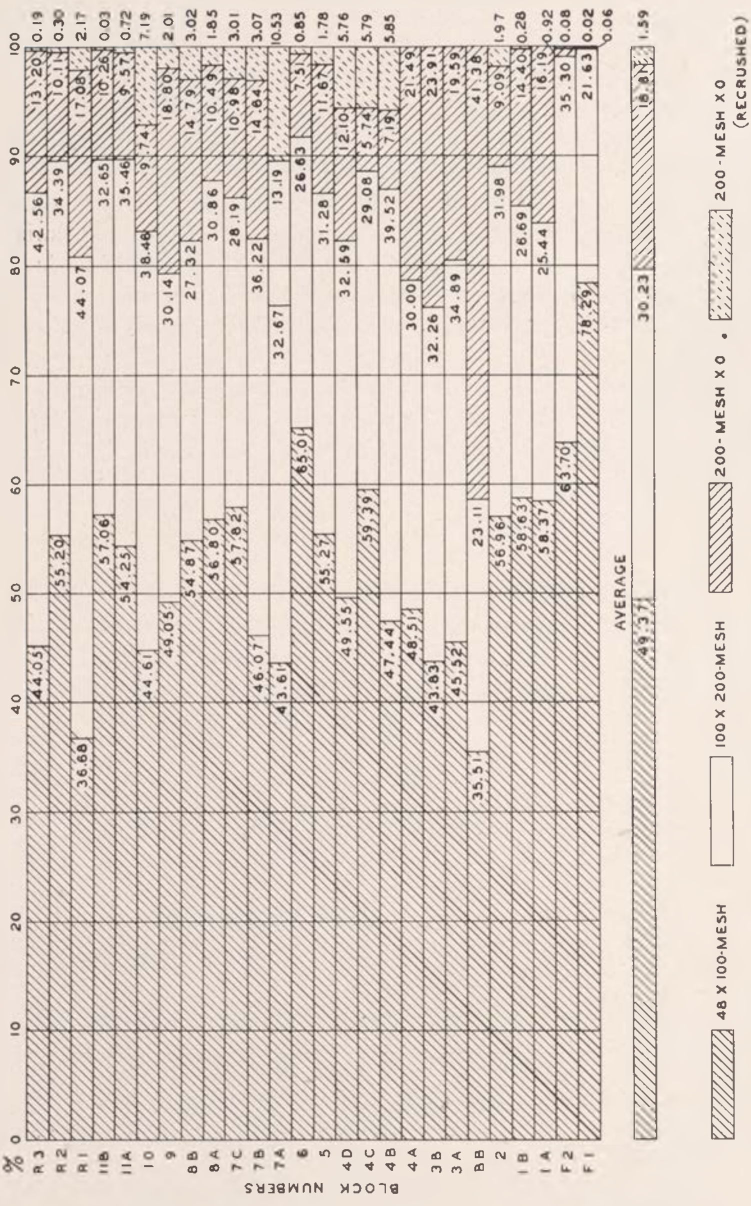

FIG. 6.—Distribution of mineral matter in each section block by screen size. (See Table 1, pp. 14-16.)

portance of the larger screen sizes and initial crushing in separating the mineral matter throughout the coal bed exclusive of the blue band. For this band the finest size is of the greatest relative importance partly because the clay band required finer crushing in order to completely pass the 48-mesh screen, and partly because of the extreme fineness of the mineral particles.

The decrease in the quantity of recoverable mineral matter with the decrease in size of the coal indicates either that most of the mineral matter occurs in larger particles or that mineral matter may be difficult to remove by the methods employed if present below a certain size. Both reasons for variation in the quantity of removable minerals may exist. Analytical determinations, however, indicate that in a crushed sample of coal the finer sizes contain less mineral matter than coarse sizes.

So far as procedure is concerned, figure 6 indicates that with respect to this coal, initial crushing to 48-mesh and smaller makes possible the separation of all but 1.6 per cent of the separable mineral matter.

DISTRIBUTION BY WEIGHT IN COAL

Details of distribution of the total quantity of separable mineral matter and of each of the four constituents with respect to the weight of the coal are shown graphically in figures 7 and 8 and in summary form in Table 8. These tabulations indicate the detail with which the examination

TABLE 8. *Summary of distribution by weight (expressed in terms of coal)*

	1 *Per cent*	2 *Per cent*	3 *Per cent*	4 *Per cent*
Total mineral matter	66.07	9.23	0.42	3.91
Calcite	2.93	5.27	0.03	0.88
Pyrite	0.02	2.93	0.003	0.44
Detrital clay	63.11	3.89	[a]0.001	1.65
Kaolinite	0.00	3.17	0.23	0.93

Column
1. Proportion of blue band mineral matter to total weight of block.
2. Maximum proportion of mineral matter to total weight of any one block.
3. Minimum proportion of mineral matter to total weight of any one block.
4. Average proportion of mineral matter to total weight of all blocks.

[a] Detrital clay absent in 5 blocks.

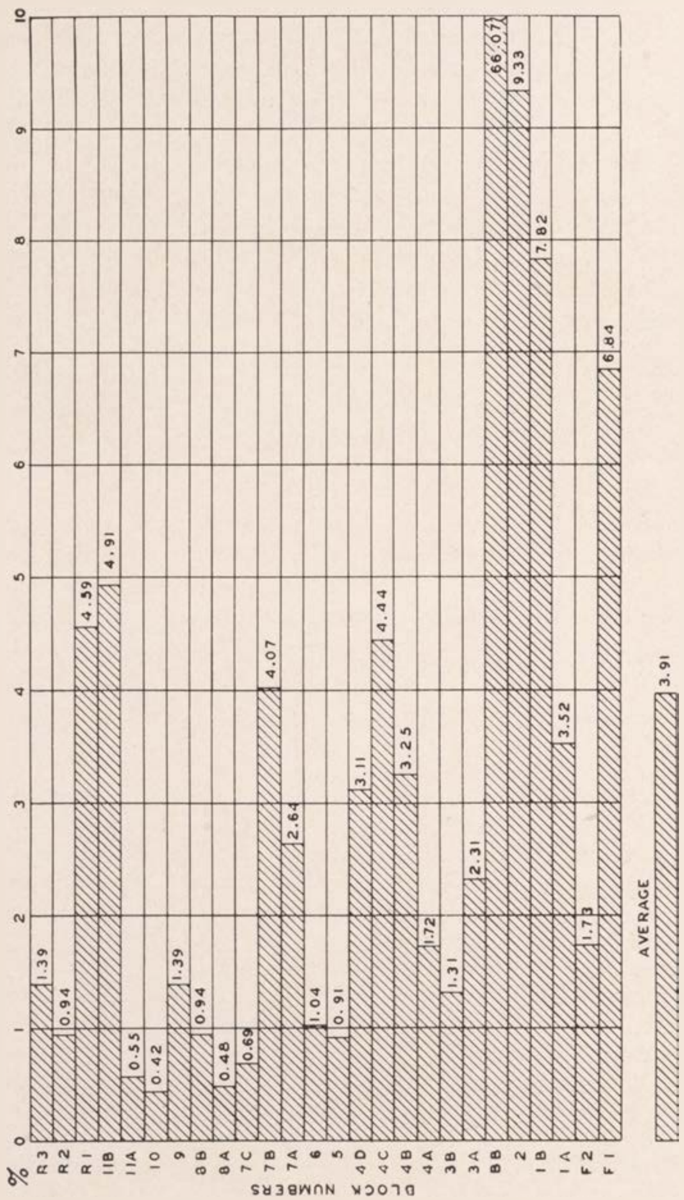

FIG. 7.—Distribution of total separable mineral matter in each section block by weight in coal.

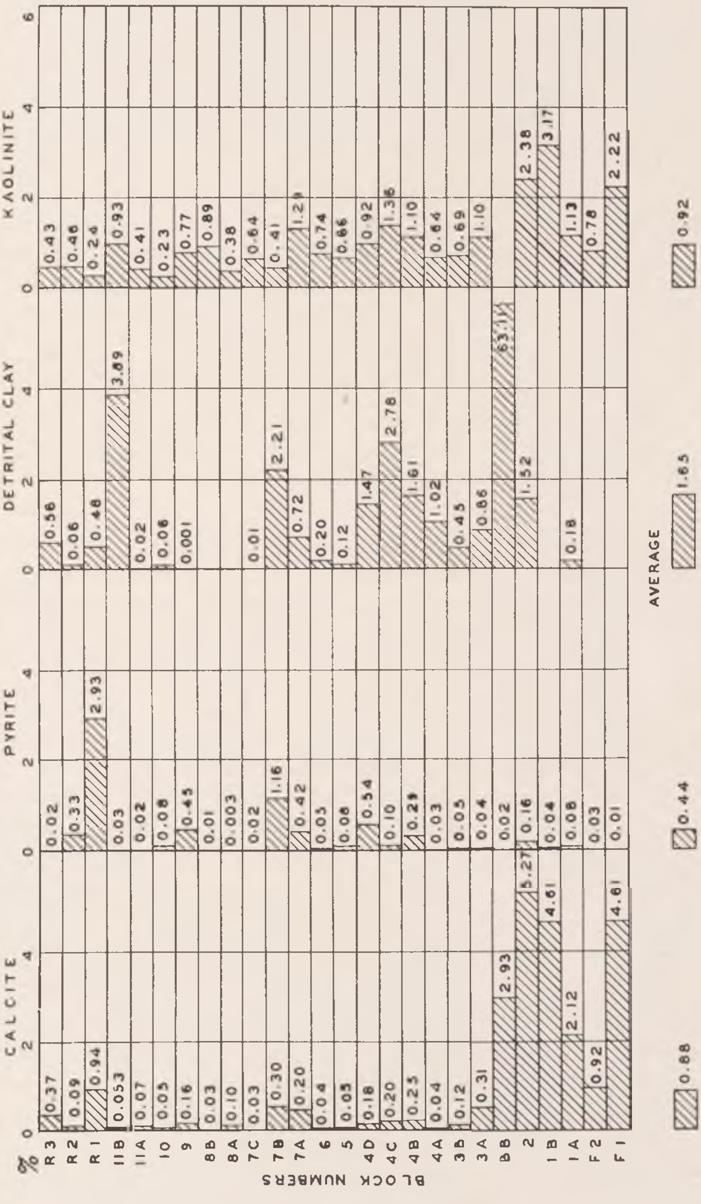

FIG. 8.—Distribution of mineral constituents in each section block by weight in coal.

was conducted and make it possible to reach certain generalizations in regard to the occurrence of mineral matter in this particular column of coal No. 6, namely:

1) The average amount of separable mineral matter in the 26 blocks is 3.91 per cent, with 8 blocks containing more and 18 blocks less than the average, with maximum and minimum values of 9.23 and 0.42 per cent respectively, exclusive of the blue band.

2) The coal containing the highest amounts of mineral matter per section block occurs at the base of the column, blocks Fl to BB, inclusive, while the blocks in which the least mineral matter is found occur in the upper half of the column, blocks 4D to R3, inclusive. Blocks 7B, 11B, and R1 of this latter group, however, contain exceptionally high mineral contents of 4.07, 4.91, and 4.59 per cent respectively.

3) The distribution of calcite shows certain peculiarities (Fig. 8). Except in block R1 (0.94 per cent) the calcite content above the blue band is uniformly less than 0.4 per cent (0.03 to 0.37 per cent); below the blue band the amounts of separated calcite vary from 0.92 to 5.27 per cent.

4) The average pyrite content is 0.44 per cent, with only four blocks, namely 4D, 7B, 9 and R1, exceeding the average. Nineteen of the remaining blocks contain less than 0.2 per cent. The maximum pyrite content is 2.93 per cent in block R1, with block 7B (1.16 per cent) containing the next largest amount.

5) Detrital clay is the most irregular of the four mineral constituents in distribution. It is absent from five blocks, but is present in amounts of more than 1.0 per cent in 8 blocks. It is the dominant component of the blue band and occurs conspicuously in blocks 2, 4B, 4C, 7B, and 11B. The distribution is largely fortuitous without evident relation to any particular position in the bed (Fig. 8).

6) Kaolinite is the most regular of the four mineral constituents in its occurrence; 18 blocks range from 0.23 to 0.93 per cent, 1 block contains over 3.0 per cent, 2 blocks from 2.0 to 3.0 per cent, and 5 blocks from 1.0 to 2.0 per cent. It is absent only from the blue band, and, like the calcite, occurs in greatest quantity below the blue band.

The abundance of mineral matter in and below the blue band and in blocks 4C, 7B, 11B, and R1, the concentration of the calcite in and below the blue band but with uniformly low content above, the great concentration of pyrite in blocks 7B and R1, the abundance of detrital clay in the middle part of the column from blocks 2 to 7B inclusive, and the similarity of kaolinite content throughout the column except for some concentration below the blue band, are all noteworthy.

DISTRIBUTION BY WEIGHT IN MINERAL MATTER

The distribution of mineral matter constituents in the bed with respect to the coal is described in the preceding section, each constituent being considered individually. The quantitative relations among the four minerals are shown graphically in figure 9, which makes possible a comparison of any two or more blocks with respect to the relative importance of each of the four mineral constituents (Table 9).

TABLE 9. *Summary of distribution by weight (expressed in terms of mineral matter)*

	1	2	3	4
	Per cent	*Per cent*	*Per cent*	*Per cent*
Calcite	4.44	67.36	1.07	22.67
Pyrite	0.04	63.75	0.21	11.34
Detrital clay	95.53	79.23	[a]0.11	42.38
Kaolinite	0.00	91.91	5.05	23.62

Column
1. Proportion of blue band mineral matter to total mineral matter in blue band.
2. Maximum proportion of mineral matter to total weight of mineral matter in any one block.
3. Minimum proportion of mineral matter to total weight of mineral matter in any one block.
4. Average proportion of mineral matter to total weight of mineral matter in all blocks.

[a] Detrital clay absent in 5 blocks.

Slightly erroneous values may be obtained for blocks that contain a small quantity of mineral matter. In the computation of the relative quantities of mineral constituents when low in amount, slight errors in weighing become relatively important so that erroneous relationships with respect to the total mineral matter may arise. For example, a constituent weight of .001 gram represents 2.00 per cent of a mineral matter weight of .050 gram, but only 0.20 per cent of a mineral matter weight of .500 gram. In the former case an error of .0005 gram for the constituent weight becomes a 1.00 per cent error with respect to its relation to the total mineral matter, whereas in the latter case an equivalent error in the weight of a constituent constitutes an analogous error of only 0.10 per cent. The somewhat high value of the calcite to total mineral matter ratio in block 8A, where the mineral matter represents only 0.48 per cent of the section block, may be partly ascribed to this effect.

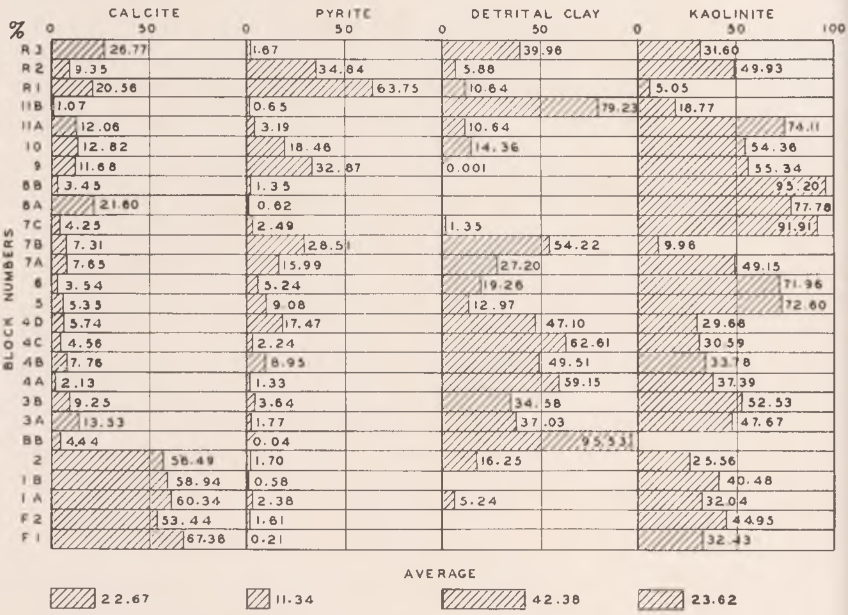

FIG. 9.—Distribution of mineral constituents in each section block by weight in mineral matter.

The distribution of relative proportions of the different minerals in the column is distinctive for various benches of the coal bed from the base of the bed upwards:

1) Bottom bench, below the blue band (blocks F1 to 2). In this part of the bed the composition of the mineral matter is uniform, with high calcite values, moderately high kaolinite values, and uniformly low pyrite values. Small proportions of detrital clay occur in blocks 1A and 2.

2) Blue band. In this band detrital clay forms 95.53 per cent of the total mineral matter, calcite 4.44 per cent, and pyrite 0.04 per cent; kaolinite is absent.

3) Blocks 3A to 4D, inclusive. This bench is characterized by a relatively high content of detrital clay (34.6 to 62.6 per cent) and kaolinite (29.7 to 52.5 per cent). Detrital clay is irregular in its variation within this bench, but both kaolinite and calcite tend to decrease in relative amount and pyrite to increase toward the top of the bench.

4) Blocks 5, 6, and 7A. In contrast to the underlying bench, the amount of kaolinite increases abruptly as indicated by values of 72.6, 72.0,

and 49.2 per cent. Detrital clay decreases in amount, with pyrite moderately high and calcite uniformly low.

5) Block 7B. This block contains high detrital clay (54.2 per cent) and pyrite (28.5 per cent). It resembles the blue band in its high clay-to-kaolinite ratio.

6) Blocks 7C, 8A, and 8B. This bench contains an unusually high percentage of kaolinite (77.8 to 95.2 per cent), detrital clay being almost completely absent.

7) Blocks 9, 10, and 11A. High pyrite values (32.9 per cent) and uniform calcite content (11.7 to 12.8 per cent) characterize this bench.

8) The four upper blocks (11B, R1, R2, and R3 forming the top bench of the bed) have no common characteristics. Block 11B is noteworthy for its high content of detrital clay (79.2 per cent) while block R1 has a high pyrite content (63.8 per cent).

The outstanding peculiarities in mineral matter distribution for the column as a whole are the high calcite and kaolinite contents of the bench below the blue band, the high detrital clay content of the bench above the blue band (blocks 3A to 4D) and of block 7B, and the uniformity of kaolinite content of the middle part of the column with the exception of block 7B.

AVERAGE MINERAL MATTER

Because of the high calcite concentration below the blue band, the presence of most of the pyrite near the top of the column in block R1, and the occurrence of the bulk of the detrital clay in and immediately above the blue band, no individual bench of the column resembles the average composition of the mineral matter for the total column (Table 9). The bench composed of blocks 3A to 4D, inclusive, most nearly approaches the average, although the kaolinite is too high and the calcite and pyrite are too low. Mining of selected benches of the coal bed would result in either better or poorer coal than the average, so far as separable mineral matter content is concerned.

CONCENTRATION WITHIN THE COLUMN

The nature of the distribution of mineral matter has been established by indicating (1) the relation of the amount of mineral matter to the screen size, (2) the quantity of the total mineral matter and of each mineral constituent in the different parts of the coal bed, and (3) the relative importance of each mineral variety throughout the column. The distribution of the mineral matter may be still further indicated by examining the total mineral matter and mineral constituents in terms of concentration (Fig. 10) rather than in quantity as in figures 7 and 8. Figure 10 is summarized in Table 10.

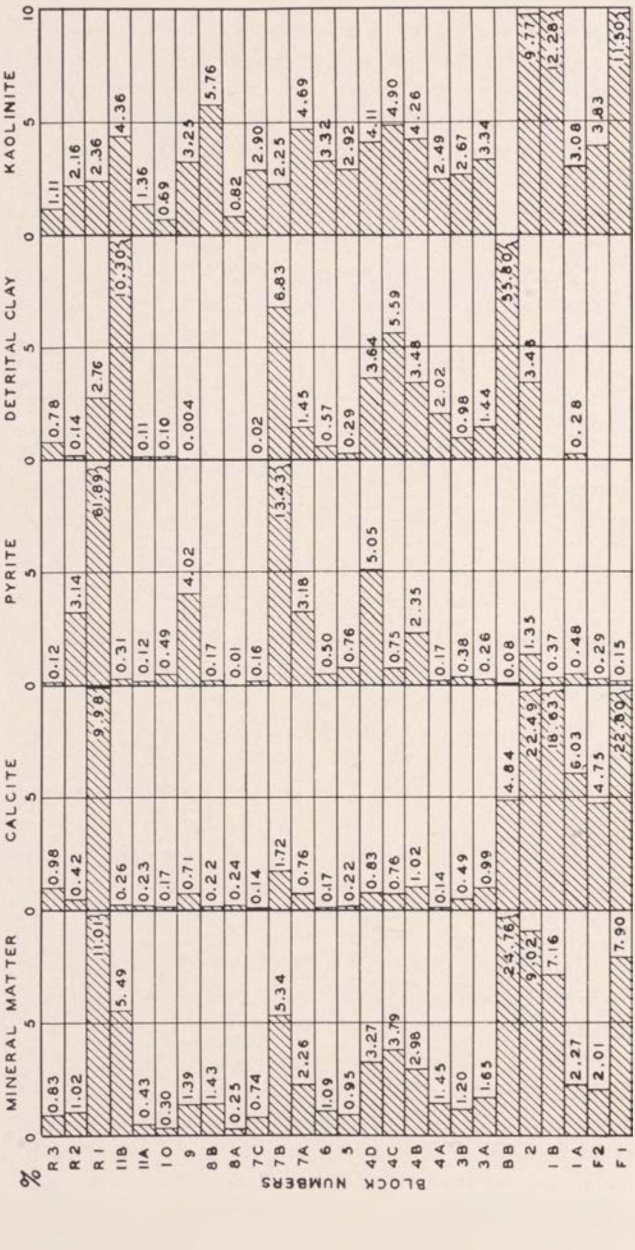

FIG. 10.—Concentration of mineral constituents within the column.

The value of such information lies in the light it throws on the amount and character of the mineral matter that would result from selective mining since it makes possible the quantitative determination of the mineral matter in any part of the bed, particularly above or below certain levels. By reference to figure 11, which shows the cumulative proportions of separable mineral matter and mineral constituents in the total column, the amount and character of the separable mineral matter in any portion of the bed may be determined. With such information available, those portions of the coal bed that contain mineral matter whose abundance and composition fall within special consumer specifications may be selectively extracted.

TABLE 10. *Summary of concentration of total mineral matter and mineral constituents*

	1	2	3
	Per cent	*Per cent*	*Per cent*
Mineral matter	24.76	11.01	0.25
Calcite	4.84	22.80	0.14
Pyrite	0.80	61.89	0.01
Detrital clay	55.80	10.30	[a]0.004
Kaolinite	0.00	12.28	0.69

Column
1. Proportion of blue band mineral matter to total mineral matter and total individual mineral constituents in the column.
2. Maximum proportion of mineral matter in any one block to total mineral matter and total individual mineral constituents in the column.
3. Minimum proportion of mineral matter in any one block to total mineral matter and total individual mineral constituents in the column.

[a] Detrital clay absent in 5 blocks.

It is apparent that the mineral matter is concentrated in certain benches, namely (1) blocks F1 to BB, inclusive, (2) blocks 4B, 4C, and 4D, (3) blocks 7A and 7B, and (4) blocks 11B and R1. These four benches, comprising 49.1 per cent of the total thickness of the column, contain 87.3 per cent of the total mineral matter.

Still greater concentration of mineral matter is indicated by the fact that seven blocks, F1, 1B, 2, BB, 7B, 11B, and R1, contain 70.7 per cent of the mineral matter, an average of 10.1 per cent for each block. With

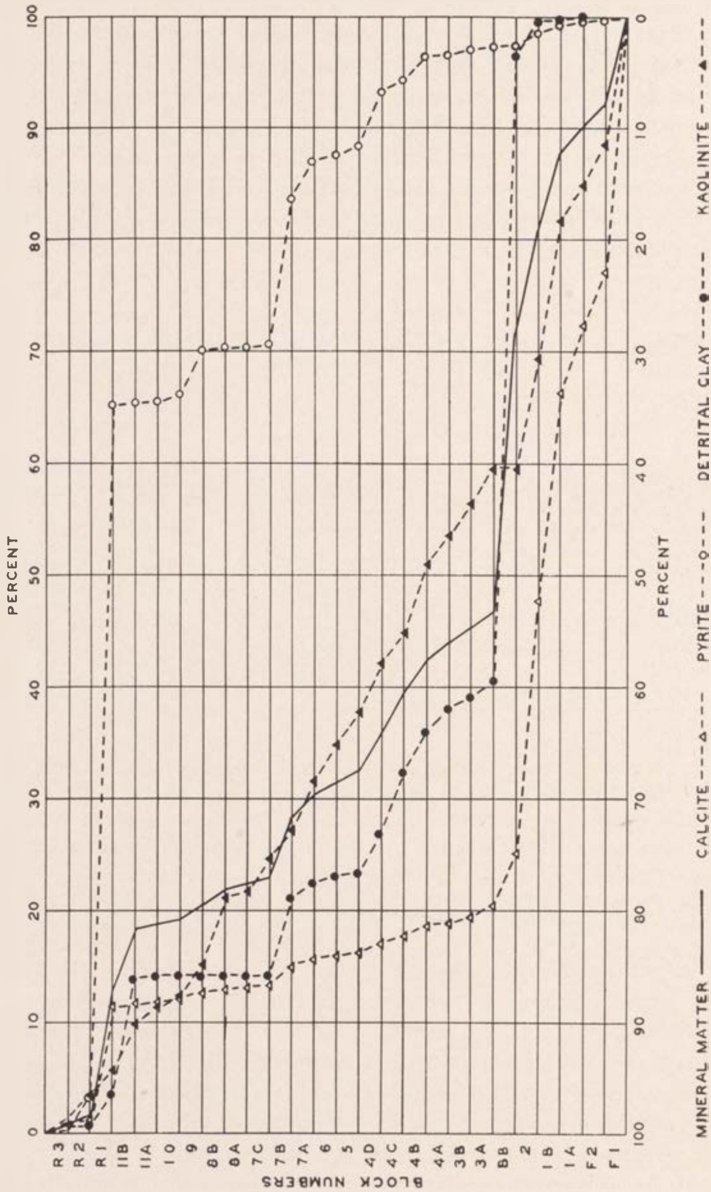

FIG. 11.—Cumulative proportions of separable mineral matter and mineral constituents in the column.

53 per cent of the total mineral matter occurring in and below the blue band, it is evident that less than 30 per cent of the total mineral matter is found in the part of the column from blocks 3A to 11A, inclusive, representing a thickness of 169.7 centimeters (66.8 inches).

The distribution of individual mineral constituents is, like the distribution of the total mineral matter, very unequal. 80 per cent of the calcite is found below the blue band, with an additional 10 per cent in block R1, leaving only 10 per cent remaining in the rest of the column. Only 35 per cent of the total pyrite is found below block R1, 25.7 centimeters below the top of the column, and nearly one-half (13.4 per cent) of this amount is confined to block 7B. The entire absence of detrital clay from five blocks has been noted. Over half of this constituent is concentrated in the blue band, and an additional 29.8 per cent is found in three narrow zones (blocks 4, 7, and 11). Kaolinite is most uniformly distributed with values generally lying between 2 and 5 per cent in each block, but with three blocks (F1, 1B, and 2) each containing from 9.8 to 12.3 per cent.

With the exception of pyrite a large part of the mineral matter in the column occurs in and below the blue band; viz., total mineral matter 53.12 per cent, calcite 79.5 per cent, detrital clay 59.5 per cent, and kaolinite 40.6 per cent. Blocks 11B and R1 contain 16.5 per cent of the total mineral matter, 10.2 per cent of the calcite, 62.5 per cent of the pyrite, and 13.1 per cent of the kaolinite. With the exception of high pyrite and detrital clay values in block 7B, the remaining portions of the column are relatively low in mineral impurities.

DISTRIBUTION OF DETRITAL NON-CLAY MINERALS

Although the four minerals to which attention has been given constitute the largest part of the mineral matter separable from the column, the distribution of the remaining mineral constituents is of interest. It is probable that much of the mineral material not removed during the laboratory separations would resemble that which was removed. Prominence of any mineral or minerals among the detrital non-clay minerals would indicate possible importance in the non-recoverable mineral matter.

Inspection of the tabulated data (Table 11) shows the conspicuously greater frequency of quartz in comparison with the other minerals. It is present in all of the 26 benches constituting the column. During microscopic examination of the mineral matter separates, blocks 2, 7A, 7C, 8A, and 8B were noted as being especially rich in quartz.

Of the minerals other than quartz, only apatite, garnet, and hornblende appear to occur in a comparably wide range. Feldspar is prevalent in most of the column below block 7A but is rare above that level. The single or scattered occurrences of the remaining mineral varieties do not suggest any particular range of distribution.

The variety of minerals present in any one position in the column is limited (Table 11). At only four levels in the column were four or more mineral species present in any one block. These positions occur in block 1A (7 varieties), blocks BB to 4B inclusive (each with 4 or more varieties), block 4D (5 varieties), and blocks 9 and 10 (6 and 7 varieties respectively). The remaining blocks of the column each contain from only one to three varieties of detrital non-clay minerals.

TABLE 11. *Identity and distribution of detrital non-clay minerals*

Block No.	Apatite	Biotite	Chlorite	Epidote	Feldspar	Garnet	Hornblende	Kyanite	Muscovite	Rutile	Quartz	Staurolite	Topaz	Tourmaline	Zircon	No. of Varieties
R3	...	...	...	...	...	...	...	...	...	...	x	...	...	...	...	1
R2	...	...	...	...	...	...	...	...	...	...	x	...	...	...	...	1
R1	...	...	...	...	...	...	...	...	...	...	x	...	...	...	...	1
11B	...	...	...	...	...	...	...	...	...	...	x	...	...	...	...	1
11A	...	...	...	...	...	x	...	...	...	...	x	...	x	...	...	3
10	x	...	...	x	...	x	x	...	..	x	x	...	...	x	...	7
9	...	x	...	x	...	...	x	...	x	...	x	...	x	...	...	6
8B	...	...	...	...	...	...	...	...	...	...	x	...	...	...	...	1
8A	...	...	...	...	...	...	x	...	...	...	x	...	...	...	...	2
7C	...	...	...	x	x	...	...	...	...	...	x	...	...	...	...	3
7B	...	x	...	...	...	...	...	...	...	x	x	...	...	...	...	3
7A	x	...	...	...	...	...	x	...	...	...	x	...	...	...	...	3
6	...	...	...	...	x	...	...	...	...	...	x	...	...	...	...	2
5	...	...	...	...	x	...	...	...	...	...	x	...	...	...	...	2
4D	x	...	...	...	x	x	x	...	...	...	x	...	...	...	...	5
4C	...	...	...	...	x	...	...	...	x	...	x	...	...	...	...	3
4B	...	...	...	...	x	x	x	...	x	...	x	...	...	...	...	5
4A	x	...	...	...	..	x	...	...	...	...	x	...	...	...	x	4
3B	x	...	x	...	x	x	x	x	x	...	x	x	...	x	x	11
3A	x	...	...	...	x	x	x	...	...	...	x	...	...	...	x	6
BB	x	...	...	...	x	x	x	...	...	x	x	...	...	...	...	6
2	...	...	...	...	x	x	...	...	...	...	x	...	...	...	...	3
1B	...	...	...	...	x	x	...	...	...	...	x	...	...	...	...	3
1A	x	x	...	...	...	x	x	x	...	...	x	...	...	...	x	7
F2	...	...	...	...	x	...	...	...	...	...	x	...	...	...	...	2
F1	...	...	...	...	...	...	...	...	...	...	x	...	...	...	...	1
Total occurrences	8	3	1	3	12	11	10	2	4	3	26	1	2	2	4	

SUMMARY

The results of the studies that have been undertaken relative to the abundance and distribution of separable mineral matter in a column of No. 6 coal from Franklin County, Illinois, may be summarized as follows:

1) Separable mineral matter in the column consists of calcite, pyrite, detrital clay, kaolinite, and non-clay detrital minerals, of which the first four constituents constitute more than 98 per cent.

2) Initial crushing of the coal so that it passes 48-mesh insures the average separation of more than 98 per cent of the removable mineral matter.

3) The amount of total mineral matter and of the individual constituents varies from bench to bench in the column.

4) The relative abundance of the individual mineral constituents varies from bench to bench in the column.

5) The data demonstrate that there is a concentration of certain mineral constituents in certain benches, resulting in very unequal distribution of the mineral impurities.

CHAPTER V—ASH

The ash of coal, as previously stated, consists of the material remaining after complete incineration, and is derived from both inherent and extraneous mineral matter. The ash derived from the extraneous mineral matter, moreover, is obtained in part from the separable mineral matter and in part from the unremovable impurities. Although the ash residue that would result from incineration of the mineral matter separable from coal may be directly computed, the source mineral matter, both inherent and extraneous, of the ash derived from the coal after mineral separation can not be specifically determined. Some indication of the identity, abundance, and distribution of these source minerals, however, may be suggested from an examination of the composition of the ash derived from coal after removal of the separable minerals, especially if based on the minerals and ash actually removed from the coal.

Ash Derived from Separable Mineral Matter

The ashing of mineral matter composed entirely of calcite, pyrite, detrital clay, and kaolinite will produce a residue of definite quantity and composition. Conversion of these specific minerals to ash, considering detrital clay as kaolinite, takes place according to the following formulae:

1) for calcite:

   $.5603 \times$ (% calcite in coal) = % CaO in coal. % Calcite = $\frac{\% \text{CaO}}{.5603}$

2) for pyrite:

   $.6655 \times$ (% pyrite in coal) = % Fe_2O_3 in coal.

3) for detrital clay and kaolinite:

   a) $.3949 \times$ (% kaolinite in coal) = % Al_2O_3 in coal.

   b) $.4660 \times$ (% kaolinite in coal) = % SiO_2 in coal.

On the basis of these relationships, the ash derived theoretically from the known separable mineral constituents of column 24 is indicated in Table 12. The variations in ratios between the separable mineral matter (Table 12, column 11) and its computed ash (column 12) are due to variations in the relative amounts of each of the four constituents in each block. The ash derived from calcite alone is 56 per cent of the

TABLE 12. *Calculated ash derived from separable mineral matter (per cent)*

Block	Calcite	CaO	Pyrite	Fe_2O_3	Detrital clay	Al_2O_3	SiO_2	Kaolinite	Al_2O_3	SiO_2	Separable mineral matter (1, 3, 5, 8)	Total ash (2, 4, 6, 7, 9, 10)
	1[a]	2[b]	3[a]	4[b]	5[a]	6[b]	7[b]	8[a]	9[b]	10[b]	11[a]	12[c]
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
R3	0.37	0.21	0.02	0.01	0.56	0.22	0.26	0.43	0.17	0.20	1.39	1.07
R2	0.09	0.05	0.33	0.22	0.06	0.02	0.03	0.46	0.18	0.21	0.94	0.71
R1	0.94	0.53	2.93	1.95	0.48	0.19	0.22	0.24	0.09	0.11	4.59	3.09
11B	0.05	0.03	0.03	0.02	3.89	1.54	1.81	0.93	0.37	0.43	4.91	4.20
11A	0.07	0.04	0.02	0.01	0.06	0.02	0.03	0.41	0.16	0.19	0.55	0.45
10	0.05	0.03	0.08	0.05	0.06	0.02	0.03	0.23	0.09	0.11	0.42	0.33
9	0.16	0.09	0.45	0.30	0.00	0.00	0.00	0.77	0.30	0.36	1.39	1.05
8B	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.89	0.35	0.41	0.94	0.79
8A	0.10	0.06	0.00	0.00	0.00	0.00	0.00	0.38	0.15	0.18	0.48	0.39
7C	0.03	0.02	0.01	0.01	0.004	0.001	0.002	0.64	0.25	0.30	0.69	0.59
7B	0.30	0.17	1.16	0.77	2.21	0.87	1.03	0.41	0.16	0.19	4.07	3.19
7A	0.20	0.11	0.42	0.28	0.72	0.28	0.33	1.29	0.51	0.60	2.64	2.11
6	0.04	0.02	0.05	0.03	0.20	0.08	0.09	0.74	0.29	0.34	1.04	0.85
5	0.05	0.03	0.08	0.05	0.12	0.05	0.06	0.66	0.26	0.31	0.91	0.76
4D	0.18	0.10	0.54	0.36	1.47	0.58	0.68	0.92	0.36	0.43	3.11	2.51
4C	0.20	0.11	0.10	0.07	2.78	1.10	1.29	1.36	0.54	0.63	4.44	3.74
4B	0.25	0.14	0.29	0.19	1.61	0.64	0.75	1.10	0.43	0.51	3.25	2.66
4A	0.04	0.02	0.03	0.02	1.02	0.40	0.47	0.64	0.25	0.30	1.72	1.46
3B	0.12	0.07	0.05	0.03	0.45	0.18	0.21	0.69	0.27	0.32	1.31	1.08
3A	0.31	0.17	0.04	0.03	0.86	0.34	0.40	1.10	0.43	0.51	2.31	1.88
BB	2.93	1.64	0.02	0.01	63.11	24.92	29.41	0.00	0.00	0.00	66.07	55.98
2	5.27	2.95	0.16	0.11	1.52	0.60	0.71	2.38	0.94	1.11	9.33	6.42
1B	4.61	2.58	0.04	0.03	0.00	0.00	0.00	3.17	1.25	1.48	7.82	5.34
1A	2.12	1.19	0.08	0.05	0.18	0.07	0.08	1.13	0.45	0.53	3.52	2.37
F2	0.92	0.51	0.03	0.02	0.00	0.00	0.00	0.78	0.31	0.36	1.73	1.20
F1	4.61	2.58	0.01	0.01	0.00	0.00	0.00	2.22	0.88	1.03	6.84	4.50
Average	0.88	0.49	0.44	0.29	1.65	0.65	0.77	0.93	0.37	0.43	3.91	3.00

[a] Determined proportions (per cent). [b] Theoretical residues (per cent). [c] Total theoretical ash (per cent).

original mineral weight, that from pyrite is 67 per cent, and that from detrital clay and/or kaolinite is 86 per cent (see conversion formulae, above).

Ash Derived from Non-Separable Mineral Matter

The determination of the relation of ash and total mineral matter in coal would be relatively simple if it could be shown that all the mineral matter is composed primarily of calcite, pyrite, detrital clay, and kaolinite as in the case of the separable mineral matter. But with the separable mineral matter representing only a portion of the total mineral content of the coal, the character, abundance, and distribution of the remaining mineral matter is therefore of much interest. The composition of the ash derived from such mineral matter is first considered.

COMPOSITION

The chemical composition of the ash remaining in the coal after separation of the recoverable minerals was determined by analyzing the ash from material floated on liquid of 1.70 specific gravity. For convenience in presentation, the column was divided into five large benches, the three middle benches representing the part of the coal bed commonly extracted in the New Orient mine. Analyses of the ash derived from each of the five benches after mineral separation is presented in Table 13.

POSSIBLE MINERAL SOURCE OF THE ASH

Although the recoverable minerals account for only a portion of the total ash in coal, it may reasonably be supposed that at least a part of the remaining ash is derived from the same varieties of minerals which are inseparable from the coal, because of their fine size and their resulting retention within the larger fragments of coal. This hypothesis may be tested by consideration of the composition of the ash remaining in the coal after removal of separable mineral matter.

In each of the five ash analyses indicated in Table 13, the oxides of calcium, iron, alumina, and silica (these being considered as possible derivatives of the minerals calcite, pyrite, and kaolinite) are present in amounts exceeding 83.7 per cent.

A disturbing factor in ash analysis, especially when large quantities of coal are ashed, is the tendency of any calcium which may be present to combine rather tenaciously with sulfur released in the oxidation of the pyrite during combustion of the coal, forming calcium sulfate.[1]

[1] Von Iw. Trifonow, Das Problem der Schwefelverteilung bei der Verbrennung von Kohle und Koks: Brennstoff-Chemie 13; (17), Sept. 1, 1932, 328-329.

TABLE 13. *Chemically determined ash composition with derived mineral matter in five benches of column 24*[a]

Bench Blocks	V R1–R3		IV 7C–11B		III BB–7B		II 1A–2		I F1–F2	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Ash composition										
SiO_2	31.08	(1.52)	50.75	(1.32)	59.40	(4.51)	38.36	(3.14)	52.33	(4.97)
Al_2O_3	16.31	(0.80)	28.19	(0.73)	25.85	(1.96)	14.30	(1.17)	13.53	(1.28)
Fe_2O_3	47.66	(2.33)	13.80	(0.36)	8.12	(0.62)	7.93	(0.65)	5.21	(0.49)
CaO	2.75	(0.13)	2.74	(0.07)	1.21	(0.09)	23.15	(1.90)	19.72	(1.87)
TiO_2	.61	(0.03)	.84	(0.02)	.76	(0.06)	.47	(0.04)	.44	(0.04)
MgO	.68	(0.03)	.76	(0.02)	1.16	(0.09)	1.67	(0.14)	1.13	(0.11)
Na_2O	.29	(0.01)	.80	(0.02)	1.19	(0.09)	1.77	(0.14)	1.10	(0.10)
K_2O	.44	(0.02)	.79	(0.02)	2.47	(0.19)	1.43	(0.12)	1.55	(0.15)
SO_3	.59		1.09		.10		11.29		5.57	
Ash	4.9		2.6		7.6		8.2		9.5	
A	97.80	(4.78)	95.48	(2.48)	94.58	(7.18)	83.74	(6.86)	90.79	(8.61)
B	98.38	(4.81)	96.53	(2.51)	94.67	(7.19)	94.40	(7.73)	96.14	(9.12)
Derived mineral matter										
1. Al_2O_3	0.80		0.73		1.96		1.17		1.28	
2. SiO_2	0.94		0.86		2.31		1.38		1.51	
3. Kaolinite	2.02	(31.37)	1.84	(60.53)	4.95	(57.03)	2.96	(31.03)	3.24	(28.95)
4. Excess SiO_2	0.58	(9.01)	0.46	(15.13)	2.20	(25.35)	1.76	(18.45)	3.46	(30.92)
5. Pyrite	3.52	(54.66)	0.54	(17.76)	0.94	(10.83)	0.98	(10.27)	0.74	(6.61)
6. Calcite	0.23	(3.57)	0.12	(3.95)	0.16	(1.84)	3.40	(35.64)	3.35	(29.94)
7. All others	0.09	(1.40)	0.08	(2.63)	0.43	(4.95)	0.44	(4.61)	0.40	(3.57)
8.	6.44		3.04		8.68		9.54		11.19	
9.	6.48		3.07		8.69		10.75		11.85	

[a] Ash analyses prepared under the supervision of Dr. O. W. Rees, Analytical Division, Illinois State Geological Survey.

TABLE 13—(continued)

A. Total SiO_2, Al_2O_3, Fe_2O_3, CaO.
B. Total of these four oxides corrected for SO_3.
1. Al_2O_3 in coal present in kaolinite.
2. SiO_2 in coal present in kaolinite.
3. Kaolinite in coal (1.16 x (Al_2O_3 plus SiO_2)).
4. Silica in coal not combined in kaolinite.
5. Pyrite in coal (1.51 x Fe_2O_3).
6. Calcite in coal (1.79 x CaO).
7. All others (sum of TiO_2, MgO, Na_2O, K_2O).
8. Sum of kaolinite, excess silica, pyrite, calcite, and all others.
9. Sum of constituent minerals corrected for SO_3.

The entire amount of calcium oxide present in the ash may be thus combined with all the sulfur available from the pyrite present. This increases the total quantity of the ash beyond that amount that would be present if the components occurred simply in the form of oxides, and is of particular importance in high-sulfur and high-calcite parts of the column. In order to put the ash values on a basis comparable with those of other tables, the values were calculated to the SO_3-free basis as indicated in Table 13. After this correction, the four oxides are evident in each of the benches in amounts exceeding 94.4 per cent.

The supposition that the four oxides which represent much of the ash might have been derived from the same mineral varieties as were separated from the coal may be further developed by the actual reconstruction of kaolinite, pyrite, and calcite from the items of the ash analyses (Table 13). The methods of calculation by which the minerals were constructed are modeled after similar conversions by G. Thiessen,[2] and consist of the following steps:

1) Since the ash analyses were given in percentages of the various components in the ash, these were converted to percentages in the coal by multiplying the percentage of the component in the ash by the percentage of ash in the coal. These values having been obtained, the following calculations were made:

2) The values for alumina were converted to silica in kaolinite by the formula:

$$1.1783 \times Al_2O_3 = SiO_2 \text{ in kaolinite.}$$

3) The kaolinite in the coal was found by:

$$1.16 \times (Al_2O_3 \text{ plus } SiO_2 \text{ in kaolinite}) = \text{kaolinite in coal.}$$

4) The difference between the total silica in the coal and the silica in the kaolinite gives excess silica.

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[2] Thiessen, G., Ash-to-mineral-matter correction in coal analyses; Illinois State Geological Survey Report of Investigations No. 32, 1934.

5) Iron oxide in the ash was converted to pyrite by:

$$1.5025 \times Fe_2O_3 = \text{pyrite in coal.}$$

6) Calcium oxide in the ash was converted to calcite in the coal by:

$$1.79 \times CaO = \text{calcite in coal.}$$

7) Titania, magnesium oxide, sodium oxide, and potassium oxide were summed up as "all others".

8) The sum of kaolinite, excess silica, pyrite, calcite, and all other components represents the mineral content of the coal based on the composition of the ash and the ash content of the coal.

9) As previously indicated, the SO_3 in the ash is not a component of a definite sulfate mineral in the original coal, and is therefore not included in the mineral content. It serves, however, to lessen the quantities of the other ash components derived from the mineral matter and must be corrected for by dividing the sum of the mineral components by (100 - SO_3) in the ash.

10) In order to indicate the proportions of each computed mineral constituent to the total calculated mineral matter, their values are also given in terms of the mineral matter.

In each bench, silica occurs in excess above the amount necessary to combine with the alumina to form kaolinite (9.01 to 30.92 per cent), and is therefore thought to exist in an uncombined state. It is not known how this silica occurs, but the two most reasonable possibilities are that it is finely divided quartz of either detrital or organic origin, although not necessarily in organic combination. This is a problem for future investigation.

The other chemical components present in the ash are represented in the calculated mineral matter in amounts not exceeding 5 per cent (1.40 to 4.95 per cent).

It is believed that if the unrecovered mineral matter consisted to any great extent of mineral substances other than the four mineral constituents composing more than 98 per cent of the recoverable minerals, recognizable amounts of such minerals should occur in sufficiently large size to be recovered. It is therefore believed that a considerable quantity of the unrecovered mineral matter consists of essentially the same minerals and that they occur in approximately the same proportions as the recoverable minerals. The above determination of the possible character of coal ash derived from coal after removal of the separable minerals lead to the conclusion that kaolinite, excess silica of highly variable amounts, pyrite, and calcite make up over 95 per cent of the mineral matter represented by the ash in the coal from which the recoverable minerals were extracted.

INHERENT MINERAL MATTER

The total amount of mineral matter, as calculated from the ash composition of the coal after removable mineral separation, includes some proportion of organically combined mineral matter. The probable amount of inherent mineral matter in coal is therefore of considerable interest, but at this time can only be approached from a theoretical standpoint, since no chemical data are available.

Modern plants require six essential mineral elements, according to Haas,[3] these being sulfur, phosphorous, potassium, calcium, magnesium, and iron. Other elements frequently necessary to modern plants include silicon, chlorine, sodium, manganese, iodine and aluminum. Comparison of the quantity and composition of the inherent ash of the coal-forming plants with that of modern plants, however, is largely speculative. The mineral requirements of the former may have differed considerably both in amount and in identity of the essential mineral elements.

A distinction between inherent and extraneous mineral matter cannot be made at the present time except to such unimportant portions of mineral elements as are actually found in organic combination. In the light of the conclusions reached in the preceding section, the amount of such inherent mineral matter, if it consists of elements other than silicon, aluminum, iron, and calcium, must be very small.

ABUNDANCE

Having considered the character and composition of the mineral matter which produces the ash remaining in the coal after separation of the removable constituents, the abundance and distribution of such mineral matter is next considered. Quantitative information on mineral matter remaining in the coal was obtained by determining the ash values in the coal remaining after mineral separation for each of the five large benches and for each of ten approximately even-spaced section blocks (Table 14). At the same time total sulfur values for each of the above ten blocks, together with total sulfur and varieties of sulfur for ten additional section blocks were determined (Table 15).

In Table 14 the theoretical ash calculated from the removable mineral matter (column 4) plus the ash obtained from the coal after removal of the separable mineral matter (column 3) represents the total ash in the coal before mineral separation (column 5). The proportions of removable ash to total ash are indicated in column 6. For the five benches ashed after removal of separable mineral matter, ash values were obtained of from 2.6 to 9.5 per cent, representing about 70 per cent (arithmetic aver-

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[3] Haas, P., Plant ash in relation to the inorganic constituent of coal: Fuel 4 (10), 1925, 424-429.

age 71.0 per cent) of the total mineral matter originally present. The separated mineral matter accordingly represents about 30 per cent of the total original mineral content.

TABLE 14. *Proximate and computed ash in five large benches and ten specific section blocks.* [a]

Location	1[a] *Per cent*	2[a] *Per cent*	3[a] *Per cent*	4 *Per cent*	5 *Per cent*	6 *Per cent*
R3–1	5.3	4.0	4.56	1.07	5.63	19.0
Bench V	....	....	*4.9*	*2.16*	*7.06*	*30.6*
10–1	3.4	3.3	3.32	0.26	3.58	7.3
8A–1	2.7	3.6	3.44	0.39	3.83	10.9
Bench IV	....	....	*2.6*	*1.24*	*3.84*	*32.3*
7B–2, 3	4.2	4.1	4.12	1.87	5.99	31.2
6–1, 2	4.7	4.1	4.19	0.85	5.04	16.9
4D–4, 5, 6	4.4	4.7	4.63	2.22	6.85	32.4
4A–3, 4	14.4	13.8	13.99	2.09	16.08	13.0
3A–3, 4, 5, 6, 7	4.9	4.0	4.30	1.88	6.18	30.4
Bench III	....	....	*7.6*	*2.04*	*9.64*	*21.2*
1B–1	7.7	7.5	7.55	5.34	12.89	41.4
Bench II	....	....	*8.2*	*4.99*	*13.19*	*37.8*
F–1	16.0	7.1	10.17	4.50	14.67	30.6
Bench I	....	....	*9.5*	*2.84*	*12.34*	*23.0*

Column
1. Ash in section block after removal of separable minerals, 200-mesh × 0 screen size of initial crushing.
2. Ash in section block after removal of separable minerals, 200-mesh × 0 screen size of re-crushing.
3. Roman figures—Weighted average (cols. 1 and 2).
   Italic figures—Ash in large bench after removal of separable minerals.
4. Theoretical ash computed from separable mineral matter.
5. Total ash (column 3 plus column 4).
6. Proportion of separable ash to total ash.

[a] Ash determinations prepared under the supervision of Dr. O. W. Rees, Analytical Division, Illinois State Geological Survey.

TABLE 15. *Sulfur in coal after removal of separable mineral matter*[a]

Block No.	1 *Per cent*	2 *Per cent*	3 *Per cent*	4 *Per cent*	5 *Per cent*	6 *Per cent*
R3–1	.....	.....	.....	2.42	2.32	2.370
R2–1	0.20	0.89	0.68	.....	.....	1.77
R1–1	1.28	2.24	0.71	.....	.....	4.23
11B–1	0.04	0.21	0.57	.....	.....	0.82
10–1	.....	.....	.....	0.89	0.86	0.875
8B–1	0.04	0.28	0.57	.....	.....	0.89
8A–1	.....	.....	.....	0.78	0.81	0.795
7C–2	0.04	0.21	0.53	.....	.....	0.78
7B–2, 3	.....	.....	.....	1.18	0.91	1.045
6–1, 2	.....	.....	.....	0.74	0.74	0.740
5–1	0.05	0.32	0.48	.....	.....	0.85
4D–4, 5, 6	.....	.....	.....	0.68	0.73	0.705
4B–4, 5	0.08	0.58	0.49	.....	.....	1.15
4A–3, 4	.....	.....	.....	0.59	0.56	0.575
3B–1, 2	0.03	0.15	0.43	.....	.....	0.61
3A–3, 4, 5, 6, 7	.....	.....	.....	0.62	0.59	0.605
2–5	0.08	0.21	0.47	.....	.....	0.76
1B–1	.....	.....	.....	0.68	0.65	0.665
F2–1	0.01	0.20	0.35	.....	.....	0.56
F1-1	.....	.....	.....	0.64	0.71	0.675

Column
1. Sulfate sulfur (200-mesh × 0 screen size of re-crushing).
2. Pyritic sulfur (200-mesh × 0 screen size of re-crushing).
3. Organic sulfur (200-mesh × 0 screen size of re-crushing).
4. Total sulfur (200-mesh × 0 screen size of first crushing).
5. Total sulfur (200-mesh × 0 screen size of re-crushing).
6. Total sulfur in section block, using the average value for those blocks analyzed by two screen sizes.

[a] Sulfur determinations prepared under the supervision of Dr. O. W. Rees, Analytical Division, Illinois State Geological Survey.

RETENTION OF MINERAL MATTER IN FINELY CRUSHED COAL

The conclusion that has been reached regarding the simple mineral composition of more than 95 per cent of the mineral matter in coal, whether separable or not, raises the question of possible reasons for the failure to obtain a larger proportion of separable mineral matter by the methods employed, since the removable mineral impurities represent only approximately 30 per cent of the total mineral content of the coal. The results of fine-grinding with relation to mineral recovery is accordingly of interest.

As previously indicated (Table 7, p. 33), the average total mineral matter yields from the 48 × 100-mesh, 100 × 200-mesh, and 200-mesh × 0 screen sizes to which the coal was originally crushed were 49.37, 30.23, and 18.81 per cent respectively, totalling 98.41 per cent. A comparison of the amounts of ash and sulfur remaining in the two 200-mesh × 0 screen sizes of coal after mineral separation (Table 14, cols. 1 and 2; Table 15, cols. 4 and 5) indicates that in general re-grinding makes it possible to recover very little more mineral matter than initial grinding sufficient to pass the coal through 48-mesh.

Since the re-crushing of the coarser screen sizes produced but little additional separable mineral matter (1.59 per cent average), and since the ash and sulfur contents of the 200-mesh × 0 screen size coal fractions of both the original and the additional crushing represent so little variation in the coal after removal of the mineral matter, it is evident that the character of the mineral matter in the finely ground coal is such as to resist recovery by the laboratory methods employed. An investigation into the possibility that such mineral matter could be further reduced by refinements of laboratory procedure, or the determination that it exists in such a state that further removal is impossible, would be of great importance to the more precise identification of the mineral constituents of coal other than those separated during the present investigation.

Although this problem was not studied further, a few generalizations concerning the possible nature and occurrence of this unremovable mineral matter may be derived from the mode of occurrence of the separable mineral constituents in those parts of the coal bed which possess high ash and sulfur contents after mineral separation.

POSSIBLE PHYSICAL NATURE OF PARTS OF THE NON-SEPARABLE MINERAL MATTER

In the ten approximately even-spaced blocks for which ash values were determined (Table 14, column 3), seven contain less than 5.0 per cent ash (3.32 to 4.63 per cent), while for the remaining blocks (F1, 1B, and 4A-3,4) the amount of ash varies from 7.55 per cent in block 1B to 13.99 per cent in block 4A-3,4. In the case of total sulfur determinations in the same ten blocks (Table 15, column 6), two blocks contain over 1.0 per cent, with the remaining blocks varying from 0.575 to 0.875 per cent. Total sulfur values in the additional ten blocks analyzed are all below 1.0 per cent except for blocks R2 and R1 with 1.77 and 4.23 per cent respectively, and block 4B-4,5 with 1.15 per cent. The total sulfur values in the three R-group blocks, representing the roof coal commonly left in the mine, are all relatively high.

Since the three high-ash blocks (F1, 1B, and 4A-3,4) and the three high-sulfur blocks (R1, R2, and R3) were considerably higher in their respective contents than the remaining blocks, it was considered that the occurrence of mineral impurities in the separable mineral matter from these blocks might afford some indication of the mineral matter remaining in the coal and giving rise to the high impurity contents.

Microscopic examination showed that a large part of the kaolinite separated from the high-ash blocks and of the pyrite from the high-sulfur blocks occurred as very slender, cylindrical fillings of fusain cavities. The pyrite, moreover, was also observed as thoroughly impregnating the organic walls of the enclosing fusain. The discovery of this intimate association of kaolinite and pyrite with fusain in the mineral separates of the high-impurity blocks in question is believed to indicate that such occurrences of mineral matter in coal greatly impede satisfactory separation; the larger and more concentrated fragments of mineral matter descend through the separating liquid, but considerable quantities of more disseminated mineral matter are left in the coal.

Since calcite also occurs in narrow fusain cavities (p. 29), it may also contribute to high-ash contents in coal after removal of separable mineral matter, although this supposition can not now be verified since the calcite was quantitatively removed from the mineral separates during the laboratory procedure (p. 18).

To what extent other types of mineral occurrences, such as deposits of calcite, pyrite, and kaolinite in the vertical desiccation cracks, and interminglings of detrital clay with the coal, contribute to the ash remaining in the coal after mineral separation can not be stated. The uniformly low ash and sulfur contents of most of the blocks analyzed after mineral separation, however, would seem to indicate that mineral matter occurring in any other manner than in fusain cavities is capable of removal in any amount until a uniform quantity of inseparable mineral matter remains in the coal. In general, except for disseminated occurrences of calcite, pyrite, and kaolinite in fusain cavities, the coal from which mineral matter has been removed possesses an ash content below 5.0 per cent. This figure apparently represents the approximate limit to which the coal can be freed of separable impurities by the described laboratory procedure.

Further inquiry into the question of whether the bulk of the unremovable mineral impurities in coal exist as disseminated mineral occurrences in fusain, or whether the limits of ash and sulfur reduction as indicated in the preceding paragraph can be further reduced, would be very desirable.

DISTRIBUTION

The data on distribution of the unrecovered mineral matter, as represented by the ash, are contained in Table 14, column 3, and Table 15, columns 1, 2, 3, and 6. Although the chemical information concerning ash and sulfur in the cleaned coal is not so detailed as that for the separable mineral matter, a few observations may be made.

The ash contents of the cleaned coal in the five benches increase markedly from top to bottom of the column (2.6 per cent in bench IV to 9.5 per cent in bench I). Bench V, although higher in ash (4.9 per cent) than the underlying bench, is lower in ash than any of the three lowest benches. The ash contents of specific blocks in the five benches in general corroborate the distribution of ash as indicated by the bench analyses. In bench III, however, four of the five blocks for which analyses were made contain uniform amounts of ash varying only from 4.12 to 4.63 per cent, while block 4A-3,4 alone contains an ash value (13.99 per cent) much higher than that in the total bench (7.6 per cent). The high-ash value for bench III, accordingly, may be due to occasional especially high-ash blocks such as 4A-3,4 and may not represent accurately the ash content of the majority of the blocks contained in the bench.

With the exception of the roof coal (blocks R1, R2, and R3) the total sulfur remaining in the cleaned coal is notably uniform (Table 15, column 6), ranging from 0.56 to 1.15 per cent. In general the total sulfur values below the roof coal decrease in amount towards the base of the column.

Sulfate sulfur (Table 15, column 1) is not abundant in freshly mined coal, as indicated by contents of 0.08 per cent or less below the roof coal, but may become important after exposure to atmospheric conditions through the oxidation of pyrite. Since the roof coal was collected in an entry of the mine which had been opened for some time, the high sulfate sulfur contents in blocks R1 and R2 may be attributed to this alteration.

Pyritic sulfur (Table 15, column 2) is uniformly low in amount (0.15 to 0.58 per cent) in the coal after mineral separation, except in blocks R1 (2.24 per cent) and R2 (0.89 per cent). The high pyrite contents of the cleaned roof coal have already been noted (p. 58).

Organic sulfur (Table 15, column 3) is by definition considered as non-removable during separation processes. Its distribution in the coal bed, however, constitutes some measure of the amounts of organic sulfur bound up in the plant material which contributed to the peat. Because of the distinct and uniform decrease in organic sulfur values from blocks R1 and R2 (0.71 and 0.68 per cent) at the top of the column to block F2 (0.35 per cent) at the base, it would seem that the vegetation of the peat swamp contained increasing amounts of sulfur towards the close of peat deposition, or that the vegetation growing in the later periods of peat deposition became enriched in sulfur at the expense of the previously deposited plant material.

In general the varieties of sulfur and total sulfur are approximately uniform in distribution through the column, with the exception of the roof coal which is especially high in pyritic and sulfate sulfur. A uniform decrease in organic sulfur from the top to the bottom of the bed is reflected by the slight decrease in total sulfur values towards the base of the column.

Comparison of the distribution of the ash and sulfur remaining in the coal after mineral separation with the distribution of the separable mineral constituents (Figs. 6 and 7) indicates that the distribution of the unremovable mineral matter as represented by the ash and sulfur values is very similar to that of the separable mineral matter. This similarity is especially marked by the increase in amounts of both unseparable and removable mineral matter towards the base of the column, by the high proportions of calcium oxide and calcite in the ash and separable mineral matter below the blue band, and by the high pyritic sulfur content of the cleaned roof coal as compared with the high pyrite content of the separable mineral matter of the roof coal.

Summary

Information on the total ash contained in column 24 may be summarized as follows:

1) The character and abundance of the ash from the separable mineral matter may be directly calculated.

2) The unremovable mineral matter is considered to consist mainly of the same three minerals which compose the bulk of the separable mineral matter, namely calcite, pyrite, and kaolinite, with the addition of variable amounts of free silica.

3) Mineral matter obtained by crushing the coal to minus 48-mesh is not materially increased by additional crushing and separation of the light fractions of the coarser screen sizes.

4) The unremovable mineral matter represents approximately 70 per cent of the total ash, the remaining 30 per cent being produced by the separable mineral matter.

5) A considerable quantity of the original mineral matter of the coal is retained within the coal fractions after separation. Part of such mineral matter consists of disseminated occurrences of calcite, pyrite, or kaolinite in fusain cavities, but the reasons for retention within the coal after fine crushing are not fully understood.

6) The distribution of the mineral matter remaining in the coal after mineral separation is similar to the distribution of the removable minerals, both in composition and in quantity.

7) Two important questions for further investigation in connection with the ash of coal have been indicated:

(a) The nature and abundance of the excess silica.

(b) The reasons for retention of a large part of the mineral matter within the coal after removal of separable mineral matter by the laboratory methods employed during this investigation.

CHAPTER VI.—ECONOMIC APPLICATIONS

Introduction

The primary purpose of this petrographic investigation of mineral matter in coal has been the determination of the character, mode of occurrence, distribution, and abundance of the mineral constituents, and the interpretation of the analyses of coal ash in terms of the original mineral impurities in the coal. This having been attained, the precise data concerning the coal minerals will provide information of especial significance to many problems concerning the combustion and utilization of coal.

Inasmuch as the accumulated information relative to mineral matter in coal has been derived from investigation of only a single column, and since the application of such data to problems of coal combustion and utilization constitute major researches beyond the scope of this study, the practical significance of the information obtained can only be suggested.

Selective Mining

The selective extraction of coal within specific beds has not been attempted, so far as the author is aware. The custom of leaving the bottom coal in the New Orient mine is based on machine-cutting practice rather than on any effort to improve the mined product. Since the coal of this bench contains a higher ash content than the remainder of the bed (Table 14), the general effect is to decrease somewhat the ash content of the coal as mined.

The information relative to the distribution and abundance of the mineral matter in column 24 suggests that the extraction of a selected portion of the coal bed would still further reduce the ash content of the coal as mined, and at the same time would favorably alter the composition of the ash. Tables 16 and 17 have been prepared to indicate the effects of such selective mining.

Table 16 presents the composition of the separable mineral matter and of the ash remaining in the coal after mineral removal, in terms of probable mineral matter, for each bench of column 24. The total ash of each bench and the fusion point of the ash remaining in the coal after mineral separation are also indicated.

TABLE 16. *Ash Characteristics of Benches*

Bench	V (Top) *Per cent*	IV *Per cent*	III *Per cent*	II *Per cent*	I (Bottom) *Per cent*
Thickness	9.49	28.70	43.16	11.49	7.16
Ash minerals[a]					
Kaolinite	31.37	60.53	57.03	31.03	28.95
Excess silica	9.01	15.13	25.35	18.45	30.92
Pyrite	54.66	17.76	10.83	10.27	6.61
Calcite	3.57	3.95	1.84	35.64	29.94
All others	1.40	2.63	4.95	4.61	3.57
Ash[b]	4.9	2.6	7.6	8.2	9.5
Separable minerals					
Kaolinite	22.49	89.53	80.56	40.73	34.97
Pyrite	57.44	6.01	12.72	1.35	0.50
Calcite	20.07	4.46	6.72	57.91	64.54
Separable ash	2.16	1.24	2.04	4.99	2.84
Total ash	7.06	3.83	9.64	13.19	12.34
Softening temp.[c]	1989	2376	2569	2080	2080[d]

[a] Calculated from composition of ash remaining in coal after mineral separation.

[b] Ash remaining in coal after mineral separation.

[c] In degrees Fahr. Softening temperature of ash remaining in coal after mineral separation.

[d] No sample available. The softening temperature of the ash of Bench II is used.

Table 17 represents the character of the separable and non-separable ash, the calculated total ash, and the calculated ash fusion temperature for (1) the total column; (2) benches II to IV, inclusive, representing the coal commonly extracted in the New Orient mine; and (3) benches III and IV, representing a portion of the coal bed with reduced ash content and favorable ash composition.

These tables indicate that by mining only benches III and IV, which constitute 72 per cent of the total height of the column and 86 per cent of the coal mined at present, the total ash would be reduced from 8.33 and 8.13 per cent to 7.32 per cent, a loss of about 10 per cent in ash content. At the same time, the mineral matter in this part of the coal bed is higher in kaolinite and excess silica, approximately equal in pyrite,

TABLE 17. *Effects of Selective Mining*

Bench groups	I–V *Per cent*	II–IV *Per cent*	III–IV *Per cent*
Thickness, to total	100.00 (106.9″)	83.35 (89.1″)	71.85 (76.8″)[a]
Ash minerals[b]			
Kaolinite	50.61	54.60	58.43
Excess Silica	20.47	20.88	21.27
Pyrite	16.61	13.14	13.60
Calcite	8.50	7.23	2.68
All others	3.81	4.15	4.02
Ash[c]	6.11	5.96	5.60
Separable minerals			
Kaolinite	69.78	78.16	84.13
Pyrite	12.86	8.84	10.05
Calcite	17.36	13.00	5.82
Separable ash	2.22	2.17	1.72
Total ash	8.33	8.13	7.32
Softening temp.[d]	2371	2435	2487

[a] The thickness of Benches III and IV represents 86.21 per cent of that of Benches II to IV, which form the coal now mined.

[b] Calculated from composition of ash remaining in coal after mineral separation.

[c] Ash remaining in coal after mineral separation.

[d] In degrees Fahr. Softening temperature of ash remaining in coal after mineral mineral separation.

and considerably lower in calcite than in the coal now mined and in the total column.

A definite effect of such a change in the composition of the mineral matter would be to increase the temperature of ash fusibility, since the mineral kaolinite and the excess silica, both representing components of relatively high fusion points, are increased at the expense of minerals with low ash fusibility. Such an increase in ash fusion temperature in the selected portion of the coal bed is indicated by its ash softening temperature of 2487° F., definitely higher than the corresponding figure for the coal mined at present, and for the total coal bed.

The fact that the separable ash of benches I, II, and V is in each case higher than that of benches III and IV suggests that the coal remaining after extraction of the selected portion of the coal bed would respond more readily to cleaning processes than the coal as mined at present. It is not known how the calorific value of the selectively mined portion of the coal bed would compare with that of the total column and of the coal as mined at present, but in view of the decrease in ash content it might reasonably be supposed to become somewhat higher.

UNIFORMITY OF OCCURRENCE OF MINERAL MATTER

The benefits to be gained by selective mining, as based on a petrographic analysis of the mineral matter in a single column of coal, are limited by the extent to which uniformity of composition, abundance, and distribution of the mineral matter exists in the coal mine. In order to determine the extent of uniformity of the occurrence of mineral matter within the mine without subjecting additional columns of coal to detailed laboratory analysis, a critical inspection of the visible mineral matter in the New Orient mine, and in the adjacent Orient No. 1 mine, was undertaken.

In these two mines, extending over approximately eleven square miles, the occurrence of visible mineral matter in freshly exposed working faces was carefully examined in seven widely separated locations. The height of the coal in each place was divided into three benches corresponding with benches II, III and IV inclusive, and, where possible, V of column 24. The minerals occurring visibly in each bench were identified, and the approximate proportion of each to the total visible mineral matter in the bench was estimated.

It was found that the visible minerals occurring in the coal throughout the mines were the same as those composing the bulk of the mineral matter in column 24. Calcite, pyrite, detrital clay, and kaolinite, accordingly, probably represent something over 95 per cent of the total mineral matter in the coal of the area in question.

The abundance and distribution of these visible mineral ingredients, moreover, were in general closely similar to the abundance and distribution of mineral matter in column 24.

In the coal of the top bench (bench V of column 24), pyrite is consistently present as the predominant mineral. Except in the vicinity of faulted zones, moreover, considerably over half of the pyrite in the total thickness of the coal bed occurs in the top coal. The abundance of the pyrite in the top bench is apparently about the same as that determined for column 24, with the exception of the far northeast corner of the mine, about one mile northeast of the location of column 24. Here calcite and kaolinite exceed the amount of visible pyrite, forming about 60 per cent of the total mineral matter.

The coal between the blue band and the top bench (benches III and IV of column 24) exhibits great uniformity in mineral matter composition and abundance. The predominant mineral is kaolinite, except in the far northeast corner of the area where calcite occurs in amount about equal to the kaolinite. The general abundance of the mineral matter in this portion of the coal bed throughout the area is very similar to that of column 24 in its relatively low mineral content with respect to the remainder of the bed.

The bottom coal, below the blue band, contains high amounts of mineral matter throughout the area, as in column 24. This mineral matter is composed of about equal amounts of calcite and kaolinite, although in the southern part of the area the proportion of calcite becomes somewhat less.

The studies of abundance and distribution of mineral matter in the two Orient mines indicate that there is a high degree of uniformity in the occurrence of mineral matter over an area of approximately eleven square miles. The mineral matter in the coal between the blue band and the top coal, the portion of the coal bed that has been suggested as suitable for selective mining, is especially uniform in mineral composition and low amount throughout the mines.

Conclusions

Complete discussion of the advisability of selective mining and the possibilities it might provide for the coal operator would necessitate detailed determinations beyond the scope of this report. It has been suggested, however, that the extraction of a selected portion of the coal bed, amounting to 86 per cent of the coal now mined, would provide coal with one per cent less ash and with an ash of more refractory composition. The introductory consideration here given to this problem provides a basis on which more specific investigations will be made in the future.

With the realization of the effects of specific mineral substances upon the possibilities of satisfactory coal cleaning and upon the behaviour of the coal ash during combustion, it is possible that the coal operator may be able economically to select portions of his coal best adapted to the needs of the consumer, such selection being based on the composition and relative abundance of the mineral matter in the coal. The distribution of mineral matter in the coal bed may render cleaning processes unnecessary for the coal in some portions of the bed, but may indicate their necessity in others. The blending of coal from two or more specific benches of a coal bed, or even from two or more distinct coal horizons may enable the operator to provide coal with ash conforming to the needs of the purchaser, especially with regard to specified ash fusion temperatures, and to maximum ash limits.

Softening Temperature of the Ash

The behaviour of ash during combustion of the coal is determined among other things by the identity of the ash-forming mineral constituents. In previous investigations of ash fusibility only the chemical composition of the ash after incineration of the coal has been considered. Realization that a large part of the mineral matter from which the chemical components of the ash have been derived consists of but three minerals—calcite, pyrite, and kaolinite—provides a definite basis for renewed investigation of this problem.

Although the significant minerals contributing to the ash of coal are so limited in number, their combustion behaviour still constitutes a complex problem. It is known that each of these three minerals breaks down into oxides at temperatures that are in general less than those commonly existing in the fuel bed (1800° to 3000° F, or 980° to 1650° C),[1] but that the resulting oxides usually possess melting points above the indicated temperatures. Mixtures of such oxides, however, commonly melt at temperatures lower than those of the individual components because of the development of eutectic relationships. Hence the relation between ash composition and its melting point becomes very involved.

Satisfactory solution of the problems of coal ash fusibility rests not only on definite information regarding the identity and relative abundance of the mineral constituents, but also upon their behaviour both singly and in mixtures at temperatures higher than their dissociation points. It is possible that efforts to control the fusion temperature of ash may be conducted along lines involving character of the mineral matter rather than quantity, especially as the limited mineral composition of the ash-forming material is realized.

Coal Preparation

Coal preparation consists of those processes whereby the coal is prepared for shipment by screening into different sizes and by eliminating some portion of the mineral matter. Coal preparation begins at the face and the procedure employed in mining and loading the coal is quite as important in determining the amount of mineral matter in the coal when loaded for shipment as the methods used at the tipple in sizing and cleaning.

The coal delivered to the tipple at Illinois mines commonly includes foreign material, a large part of which is derived from the roof, floor, and

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[1] Sherman, R. A., A study of refractory service conditions in boiler furnaces. U. S. Bureau of Mines, Bull. 334, 1931, 27-56.

clay and pyrite bands in the coal bed, and is extraneous to the coal itself. The remainder of the mineral matter consists of the component minerals discussed in this report. Even in cases where the cleaning problem consists to an important extent in the removal of such component minerals, it is not yet apparent that under present methods of cleaning, variations in the identity and manner of occurrence of these minerals are important considerations in effecting ash reduction or in determining the loss in the cleaning operation. Further experimental and observational data concerning the possibility and the effect of the differential separation of the minerals are essential to definite conclusions with respect to this problem.

With respect to the character of the ash as contrasted with its quantity, however, knowledge of the nature of the component minerals may be of some significance. It is shown in Table 16, p. 64, that an increase in the relative amount of kaolinite present in the coal apparently causes the ash to soften at a higher temperature. If the cleaning process tends to accomplish removal of pyrite more effectively than the removal of kaolinite, there would be an increase in the amount of this more refractory mineral in the cleaned coal. Although it is probably true that the cleaned portion of the coal would have a higher softening temperature than the reject material, it is conceivable that the mineral matter might occur in such a way that the reject would be more refractory than the cleaned coal. This would occur particularly if the pyrite is so finely disseminated and the cleaned coal of such a size that a larger proportion of kaolinite than of pyrite is removed by cleaning.

Evaluation of Ash-Correction Formulae

The results obtained from the detailed petrographic study of the mineral constituents of column 24 have justified certain generalizations in regard to the validity of ash-correction formulae in common use for deriving mineral-free values from the items of the proximate analyses, such values being the approved basis of scientific classification of coal by rank. The following section of this report has been independently presented before the Society of Economic Geologists in December, 1933, at Chicago, Illinois.[2]

USE OF MINERAL MATTER DETERMINATIONS IN CHECKING ASH-CORRECTION FORMULAE

It has long been recognized that comparison of coals is most satisfactory when using mineral-free values calculated to either the moist or

[2] Ball, C. G. and Cady, G. H., Evaluation of ash correction formulae based on petrographic analyses of mineral matter in coal: Econ. Geol. vol. 30, 1935, 72-88.

the dry basis. The computation of such values depends upon the preliminary determination of the theoretical mineral matter values. The formula which has met with the greatest approval in the derivation of mineral matter values from the items of the proximate analyses is expressed in the ash correction portion of the Parr unit coal formula:[3]

$$\text{Mineral matter} = 1.08 \times \text{Ash} + .55 \times \text{Sulfur}.$$

In this and following formulae ash, sulfur, and other values are given as fractions of unity.

The Parr formula is based upon the assumptions (1) that all mineral matter is composed of clay and pyrite, (2) that all of the sulfur is pyritic, and (3) that water of hydration in the clay is 8 per cent. None of these assumptions is correct and the calculated value for mineral matter may be considered erroneous unless the errors compensate one another or are so small as to be unimportant. Confidence in the approximate accuracy of the Parr ash correction formula rests upon uniformity of unit coal values, derived by its use, particularly the unit calorific values, over a considerable area such as a county. Assuming the validity of the premise that such uniformity of the pure coal exists, any formula which will give uniform values should be regarded with favor. There is no reason to question the validity of the premise and, for the purposes of this presentation it is therefore assumed to be correct.

Even though the results obtained by the use of the Parr formula are prevailingly satisfactory, the fact that irregularities in unit coal values are found, that the formula itself is obviously theoretically inaccurate, and the further possibility that regional variations in unit coal values may be inaccurately indicated due to regional variation in the character and amount of the ash, makes advisable critical examination of the formula from time to time as knowledge of the actual mineral composition of the coals improves. In the following paragraphs, therefore, critical consideration is given to the ash-correction portions of the Parr formula as given above and to a form of the Parr formula slightly modified by Thiessen[4] which provides a somewhat different correction for the presence of calcite in the coal than that originally proposed by Parr. This modified ash correction formula is stated as follows:

$$\text{Mineral matter} = 1.08\ \text{Ash} + .9 \times CO_2 + .55 \times \text{Sulfur}.$$

EVALUATION OF THE PARR FORMULA

Assuming that the mineral matter is composed entirely of kaolinite, calcite, and pyrite, ashing will produce a theoretical residue composed of

[3] Parr, S. W., The classification of coal: Univ. of Illinois Eng. Exp. Sta. Bull. 180, 1928, p. 11.

[4] Thiessen, G., and Reed, F. H., Studies of the graphical method for calculating pure coal calorific values. Fuel, vol. 13, 167-175, 208-217, June-July, 1934; Illinois State Geol. Survey Rept. Investigations No. 32, 1934.

alumina, silica, calcium oxide, and ferric oxide, to each of which definite values can be assigned and whose sum equals the total amount of theoretical ash. If the Parr ash correction formula is then applied to this theoretical ash value, the resulting calculated mineral matter value should coincide with the actual total mineral matter value, provided that the formula is correct. In view of the obvious lack of definite relationship between terms of the Parr formula and the mineral constituents present, it is inconceivable that there will be perfect agreement, although agreement may be relatively close because of compensating errors in the formula, and the formula may be accepted as generally applicable. At any rate the possibility of considerable deviations arising from the use of the formula requires examination.

MINERAL-MATTER-TO-ASH RATIO

It is evident that the critical consideration in evaluating the formula is the ratio of mineral matter to ash. This should agree closely with the ratio between determined mineral value and the theoretical ash derived therefrom. A definite theoretical ratio exists if the mineral matter consists entirely of one constituent. For kaolinite this ratio is 1.16; for pyrite 1.51; and for calcite 1.79. The greatest possible theoretical variation in the ratio is therefore from 1.16 to 1.79.

The mineral-matter-to-ash ratio as determined by the Parr formula may be expressed as follows:

$$\frac{\text{Mineral matter}}{\text{Ash}} = 1.08 + .55 \times (\text{Sulfur/Ash})$$

It is apparent from this manner of expression of the relationships that the mineral-matter-to-ash ratio can never be less than 1.08 and that the amount by which it exceeds 1.08 will be determined entirely by the ratio of sulfur to ash. This ratio in Illinois coals ranges for county average values from .10 to .64, the average ratio being .36. In certain instances the amount of the sulfur and ash are equal and the sulfur ratio is 1.00. With such a high ratio of sulfur to ash, the mineral-matter-to-ash ratio becomes 1.63 $(1.08 + .55 \times 1.00)$. The probable range of variation, however, is between about 1.13 and 1.43 (for S/A ratios of .10 and .64 respectively), with a theoretical range of 1.16 to 1.79. However, this wide theoretical range should be cut down to about 1.16 to 1.56 because calcite is rarely present in an amount greater than 1/5 of the ash. It appears, therefore, that the ash correction formula applied to Illinois coals will give a range in the mineral-matter-to-ash ratios closely comparable with that theoretically obtained from various proportions of calcite, pyrite, and kaolinite in the amounts in which these are present in Illinois coals.

THEORETICAL ERRORS IN THE PARR FORMULA

In view of the general agreement in the range of variation of the mineral-matter-to-ash ratios as described above, it is of importance to know whether the variations in the ratios obtained by the Parr formula will be of the same nature as the theoretical variations. Possibility of disagreement arises theoretically from three causes: (1) the moisture correction factor (.08) is not the same as the moisture correction factor for the ash of kaolin; (2) the reported sulphur is not all pyritic and the relative amount of pyritic sulfur varies considerably; and (3) no allowance is made for the presence and variations in amounts of calcite.

(1) *The moisture correction factor.*—The low moisture correction factor (.08) tends to make all mineral-matter-to-ash ratios lower than the theoretically correct ratios and is of particular importance in the case of coals containing a large proportion of kaolinite. Since coals containing much kaolinite are usually low-sulfur coals, the calculated mineral-matter-to-ash ratio in low-sulfur and low-ash coals in general tends to be lower than the actual ratio, resulting in pure coal values somewhat too low for such coals.

(2) *Pyrite versus total sulphur.*—One effect of regarding all the sulfur as pyritic is to assign too small a part of the ash to kaolinite. This, however, has the compensating effect of offsetting the low moisture correction factor used for clay. A second effect is to raise the sulfur-to-ash ratio, thereby also increasing the mineral-matter-to-ash ratio. The combined effect of allotting all the sulfur to pyrite is to overcome the deficiency in the ratio due to the smallness of the correction factor for clay minerals as described under (1) above. Indeed it may be sufficient to overcome the deficiency in the ratio due to failure to make allowance for calcite.

(3) *Disturbing effect of calcite.*—The effect of making no allowance for the presence of calcite is a tendency to produce a mineral-matter-to-ash ratio which is lower than the theoretical ratio, since the carbon dioxide required for combination with calcium oxide has ten times the weight of the moisture of hydration necessary for the same weight of clay. The county average CO_2/ash ratio for Illinois coals is .07 with variations from a minimum of .02 to a maximum of .16 for the county average values. Such ratios will increase the mineral-matter-to-ash ratio .06, .02, and .14 respectively, representing the approximate deficiency in the ratio when no allowance is made for calcite.

This deficiency may be important in coals containing relatively little pyrite but much kaolinite or calcite, such as the low-sulfur coals. On the other hand it may be largely compensated for in coals in which the sulfur is high, particularly if the sulfur-to-ash ratio is high.

Of greatest significance are the irregularities due to the highly erratic occurrence of the calcite. Samples of coal from two contiguous parts of the same bed may vary considerably in their calcite content without much variation either in the amount of sulfur or in the total amount of ash. By the Parr formula the mineral-matter-to-ash ratio would be the same for the ash of both samples, whereas the theoretical ratio would be considerably higher for the high calcite coal, since the calcite is obviously displacing kaolinite. Unless a carbon dioxide determination has been run on each sample, there would be no means of determining the cause of the possible discrepancies in the unit coal values. In general it is apparent that since regarding all sulfur as pyritic tends to overcompensate the small allowance for water of hydration of the clay, the failure to make a correction for calcite is most significant in the case of low-sulfur coals and those with a low sulfur-to-ash ratio since ash from such coals will be derived largely from kaolinite or calcite or both.

CONCLUSIONS

The general conclusions in regard to the mineral matter values derived by the Parr formula, assuming that the minerals are calcite, pyrite, and kaolinite, and that the ash consists of the oxides represented in the minerals, are as follows:

(1) The Parr formula gives mineral matter values that are lower than the theoretically correct values if the sulfur content of the coal and the sulfur-to-ash ratio are low. This would result in relatively low unit coal values.

(2) This error for low-sulfur coals is still further increased if such coals contain calcite.

(3) In coals having ash of intermediate character with respect to the sulfur content it seems probable that the error due to assigning all of the sulfur to pyrite essentially compensates the deficiency due to the low value assigned to the water of hydration of the clay. Erratic variations in calcite, however, effect erratic variation in the mineral-matter-to-ash ratios of this group that are largely a matter of chance.

4) In high-sulfur coals and coals in which the sulfur-to-ash ratio is high, there is considerable chance that mineral-matter-to-ash ratios will be higher than the theoretically correct values because all the sulfur is assigned to pyrite. This is less likely to be the case, however, when considerable calcite is present which is a reasonable probability.

5) The general conclusion is that there is a reasonable probability of obtaining mineral matter values which are in close accord with the theoretically correct values using the Parr formula except possibly in the case of low sulfur coals and particularly those having a low sulfur-to-ash ratio.

EVALUATION OF THE THIESSEN FORMULA

The Thiessen formula is identical with the Parr formula except that it corrects for the presence of calcite. It is obvious that in every instance in which calcite is present this will increase the mineral-matter-to-ash ratio. It has been shown that need for such increase apparently does not exist for Illinois coals except in the case of the low sulfur coal, particularly those having a low sulfur-to-ash ratio. We have not the information at present that enables us to tell the exact limits within which this correction should be applied.

It has been observed that calcite probably effects considerable irregularities in the mineral matter values in the high-sulfur coals but it has also been shown that departures from the theoretically correct values are due largely to the deficiency of calcite rather than to its presence. If deficiencies in calcite occur the sulfur correction over-compensates the error arising from the small hydration factor for clay. If calcite were present this over-compensation would be less probable. Since calcite is usually present, the general application of the calcite correction would probably result in an average excess of mineral matter values.

APPLICATION TO DETERMINED VALUES

In order to demonstrate some of the characteristics of the values derived by the Parr and the Thiessen formulae, the results obtained by the application of the formulae to the theoretical ash are compared with the amounts of the determined mineral matter as found in the New Orient coal. For convenience of presentation column 24 is divided into five benches (Table 13, p. 52), each of which are considered separately. In Table 18 are given the following data:

(1) The separable mineral matter in each bench (from Table 12),

(2) The theoretical ash value derived from the minerals shown in Table 12,

(3) The amount of derived pyritic sulfur (Table 12),

(4) The additional amount of organic sulfur in the coal as determined by chemical analysis,

(5) The total sulfur (column 3 plus column 4),

(6) The derived mineral carbon dioxide (CO_2) (from Table 12),

(7) Determined mineral-matter-to-theoretical-ash ratios, these being regarded as theoretically accurate,

Using the above data and the Parr and Thiessen formulae, the following values are obtained:

(8) and (9) calculated ash and mineral-matter-to-ash ratios using the Parr formula and the values for pyritic sulfur,

TABLE 18. *Mineral-matter-to-theoretical-ash ratio compared with ratios obtained by formula*

Block No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
								Parr				Thiessen			
	MM	Ash	S_P	S_O	S_T	CO_2	MM: Ash	With S_P [a]		With S_T [b]		With S_P [c]		With S_T [d]	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	Col. 1 / Col. 2	MM *Per cent*	Col. 8 / Col. 2	MM *Per cent*	Col. 10 / Col. 2	MM *Per cent*	Col 12 / Col. 2	MM *Per cent*	Col. 14 / Col. 2
V	3.15	2.16	0.97	0.70	1.67	0.28	1.46	2.86	1.33	3.23	1.50	3.12	1.45	3.50	1.62
IV	1.49	1.24	0.05	0.58	0.63	0.03	1.20	1.37	1.10	1.70	1.36	1.39	1.12	1.71	1.38
III	2.51	2.04	0.17	0.42	0.59	0.07	1.23	2.30	1.14	2.52	1.24	2.36	1.17	2.59	1.27
II	7.30	4.99	0.05	0.34	0.39	1.86	1.46	5.42	1.086	5.60	1.12	7.09	1.426	7.28	1.46
I	4.27	2.84	0.01	0.35	0.36	1.21	1.50	3.07	1.082	3.26	1.15	4.16	1.472	4.35	1.54
II-IV	2.79	2.15	0.11	0.45	0.56	0.30	1.30	2.38	1.11	2.63	1.22	2.65	1.24	2.90	1.35
I-V	2.98	2.22	0.24	0.48	0.72	0.38	1.34	2.53	1.14	2.79	1.26	2.87	1.29	3.13	1.41

[a] $MM/Ash = 1.08 + .55\ S_P/Ash$

[b] $MM/Ash = 1.08 + .55\ S_T/Ash$

[c] $MM/Ash = 1.08 + .55\ S_P/Ash + .9\ CO_2/Ash$

[d] $MM/Ash = 1.08 + .55\ S_T/Ash + .9\ CO_2/Ash$

(10) and (11) calculated ash and mineral-matter-to-ash ratios using the Parr formula and values for total sulfur,

(12) and (13) calculated ash and mineral-matter-to-ash ratios using the Thiessen formula and values for pyritic sulfur,

(14) and (15) calculated ash and mineral-matter-to-ash ratios using the Thiessen formula and the values for total sulfur.

The values given in Table 18 substantiate the generalizations previously made in regard to the usefulness of the Parr formula. The variations in mineral content represented are considerable; kaolinite ranges from 35 to about 90 per cent, pyrite from one-half of one per cent to 57 per cent, and calcite from 4½ per cent to 65 per cent. This is about as wide a variation in the proportion of the mineral as one would expect to find in even a wide variety of coals. The values may be considered bench by bench:

Bench V.—This mineral matter consists of a high proportion of pyrite and equal portions of kaolinite and calcite. The best agreement is obtained by the Thiessen formula using pyritic sulfur. The Parr value is high indicating an over-correction due to regarding all sulfur as pyritic.

Bench IV.—The mineral matter is largely kaolinite with little pyrite and calcite but with a high sulfur-to-ash ratio because of the low ash. The Thiessen formula using pyritic sulfur gives the best agreement, indicating that the sulfur correction for the Parr formula considerably overcompensates for the error in the hydration factor and that additional correction for calcite is undesirable.

Bench III.—This is a high kaolinite, medium pyrite, and low calcite ash. The best agreement is with the Parr formula, indicating that a relatively small amount of total sulfur will tend to correct errors in the hydration factor. Since pyrite is commonly present in a greater amount than this in Illinois coals, the Parr formula probably gives results that are usually too large for such coals.

Bench II.—This is a high calcite, medium kaolinite, and low pyrite coal. The Parr value is very low. This is the type of mineral matter to which the Parr formula is least adapted and the Thiessen formula best adapted, since a correction for calcite is essential for agreement with the theoretically correct value.

Bench I.—This mineral matter is essentially similar to that found in Bench II, and the results substantiate those obtained for Bench II.

Benches II to IV.—The average character of these benches provides mineral matter relatively high in kaolinite and calcite and low in pyrite. As is to be expected, the Parr values are low, but the application of the calcite correction (column 15) although it gives the best agreement, is rather high, indicating that with a slightly higher sulfur value the calcite correction would probably be superfluous.

Benches I to V.—This represents the entire seam with mineral matter content that is more or less intermediate. The Parr value is too low but the Thiessen formula gives a value almost equally too high. It is apparent that whether or not the calcite correction is advisably applied to these coals is largely a matter of chance if no information in regard to the character of the ash is available aside from that supplied by the CO_2 determination.

These studies indicate that for an ash derived from the three minerals predominating in New Orient coal, the Parr formula using total sulfur values gives mineral-matter-to-ash ratios which are in satisfactory agreement with theoretical values for coals having an ash of an intermediate character (Bench III). When the kaolinite and calcite values are high, particularly when calcite is high, and the sulfur-to-ash ratio is relatively low, the Parr formula gives values which are distinctly lower than the theoretical values and a correction for calcite is desirable (Benches I and II). Coals which are relatively high in pyrite yield an ash which, corrected by the Parr formula, gives values that are relatively high (Bench V). This is particularly the case if the sulfur-to-ash ratio is high (Bench IV). Such a relationship is likely to exist in coals with low pyritic but high total sulfur. It is important to realize that with respect to sulfur it is the sulfur-to-ash ratio that is important and not the sulfur content. Ordinarily, however, the coals high in pyrite have a fairly high sulfur-to-ash ratio. Low-sulfur coals will have a high sulfur-to-ash ratio only when the ash is unusually low.

SUMMARY

The systematic separation of the mineral constituents by physical means from a column of representative Illinois coal justifies certain conclusions in regard to the prevailing constitution of the mineral components. The predominating minerals in the coal are calcite, pyrite, and kaolinite. Chemical analysis of the ash indicates the presence in some instances of considerable amounts of silica, the nature of which is unknown. Other mineral substances are present in unimportant quantity.

On the assumption that the quantity of the predominating minerals—calcite, kaolinite, and pyrite—largely determines the quantity of the ash, consideration has been given to the validity of the Parr unit coal formula as a means of providing an approximately accurate mineral matter value from the items of the proximate analysis. The studies indicate that this formula, although theoretically erroneous in detail, contains compensating errors so that it will probably yield fairly satisfactory results for coals of average ash composition. Serious errors may result, however, in determ-

ining mineral matter values for coals containing much kaolinite or calcite or both, particularly if the ratio of sulfur to ash is very low. Mineral matter values for such coals will be too low. On the other hand, values obtained from high-sulfur coals, particularly if the ratio of sulfur to ash is high, are likely to be higher than the theoretically accurate values. A general correction for calcite, such as is represented by the Thiessen formula, seems undesirable but might wisely be applied to the low-sulfur coals, particularly if the sulfur-to-ash ratio is low.

The effect of a quantity of free silica in the mineral matter has not been considered, but since it would not change in ashing, the general effect would be to compensate for errors in the hydration factor of the clays, particularly in the high-kaolinite coals, thus making the correction for calcite somewhat less necessary. It is hoped that further investigation will provide more definite data in regard to the character of this constituent and the nature of its occurrence in coal.

Conclusions

The practical applications of the petrographic investigation of mineral matter in coal as outlined above represent the more obvious contributions to be made by this type of study of the fundamental constitution of coal. Other applications will necessarily be less obvious and hence somewhat difficult to discover, although none the less real. Information of the type supplied by the present investigation becomes more and more important as it increases in extent. It is believed that additional studies of the lateral variations of mineral matter composition in No. 6 coal as well as similar investigations of the mineral matter content of older and younger coals in the Illinois coal basin will greatly increase the apparent need for petrographic information on mineral matter in coal.

APPENDIX

COMPUTED RELATIONSHIPS OF MINERAL MATTER, MINERAL CONSTITUENTS, AND ORIGINAL COAL

I. Total separable mineral matter

A. For each screen size and their total

$$\%\ \text{section block} = \frac{\text{weight of mineral separate}}{\text{weight of coal in section block}} \times 100$$

$$\%\ \text{mineral matter in block} = \frac{\text{weight of mineral separate}}{\text{weight of total mineral matter in block}} \times 100$$

B. For total mineral matter in block

$$\%\ \text{total mineral matter in column} = \frac{\text{weight of mineral separate}}{\text{weight of total mineral matter in column}} \times 100$$

II. Each constituent (calcite, pyrite, detrital clay, kaolinite)

A. For each screen size and their total

$$\%\ \text{section block} = \frac{\text{weight of mineral constituent}}{\text{weight of coal in section block}} \times 100$$

$$\%\ \text{mineral matter in block} = \frac{\text{weight of mineral constituent}}{\text{weight of total mineral matter in block}} \times 100$$

B. For total constituent

$$\%\ \text{total constituent in column} = \frac{\text{weight of mineral constituent}}{\text{weight of total mineral constituent in column}} \times 100$$

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-F1			
Height in mm	....	....	....	....	89.0
Per cent height of column	....	....	....	....	3.28
Weight in grams	32.895	17.930	24.111	....	74.936
Per cent weight of column	....	....	....	....	4.51
MINERAL MATTER:					
Weight in grams	4.011	1.108	.003	.001	5.123
Per cent section block	5.35	1.48	0.004	0.001	6.84
Per cent MM in block	78.29	21.63	0.06	0.02	100.00
Per cent MM in column	....	....	....	....	7.90
CALCITE:					
Weight in grams	2.503	.845	.0025	....	3.3505
Per cent section block	3.47	1.13	0.003	....	4.61
Per cent MM in block	50.81	16.49	0.05	....	67.36
Per cent calcite in column	....	....	....	....	22.80
PYRITE:					
Weight in grams	.010	.001	tr	....	.011
Per cent section block	0.01	0.001	0.00	....	0.01
Per cent MM in block	0.19	0.02	0.00	....	0.21
Per cent pyrite in column	....	....	....	....	0.15
DETRITAL CLAY:					
Weight in grams	....	....	....	....	....
Per cent section block	....	....	....	....	....
Per cent MM in block	....	....	....	....	....
Per cent clay in column	....	....	....	....	....
KAOLINITE:					
Weight in grams	1.498	.262	.0015	....	1.7615
Per cent section block	1.86	0.35	0.002	....	2.22
Per cent MM in block	27.29	5.11	0.03	....	32.43
Per cent kaolinite in column	....	....	....	....	11.50

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-F2			
Height in mm.	....	....	....	....	105.5
Per cent height of column.	....	....	....	....	3.89
Weight in grams.	28.198	22.052	25.359	....	75.609
Per cent weight of column.	....	....	....	....	4.55
MINERAL MATTER:					
Weight in grams.	.832	.461	.012	.001	1.306
Per cent section block.	1.10	0.61	0.015	0.001	1.73
Per cent MM in block.	63.70	35.30	0.92	0.08	100.00
Per cent MM in column.	....	....	....	....	2.01
CALCITE:					
Weight in grams.	.450	.240	.008	....	.698
Per cent section block.	0.59	0.32	0.01	....	0.92
Per cent MM in block.	34.46	18.38	0.61	....	53.44
Per cent calcite in column.	....	....	....	....	4.75
PYRITE:					
Weight in grams.	.009	.010	.002	....	.021
Per cent section block.	0.01	0.01	0.003	....	0.03
Per cent MM in block.	0.69	0.77	0.15	....	1.61
Per cent pyrite in column.	....	....	....	....	0.29
DETRITAL CLAY:					
Weight in grams.	....	....	....	....	....
Per cent section block.	....	....	....	....	....
Per cent MM in block.	....	....	....	....	....
Per cent clay in column.	....	....	....	....	....
KAOLINITE:					
Weight in grams.	.373	.211	.003	....	.587
Per cent section block.	0.49	0.28	0.004	....	0.78
Per cent MM in block.	28.56	16.16	0.23	....	44.95
Per cent kaolinite in column	....	....	....	....	3.83

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-1A-	**(1-4)**		
Height in mm	....	....	....	....	85.0
Per cent height of column	....	....	....	....	3.13
Weight in grams	....	....	....	....	41.767
Per cent weight of column	....	....	....	....	2.52
MINERAL MATTER:					
Weight in grams	.858	.374	.238	....	1.470
Per cent section block	2.05	0.89	0.57	....	3.52
Per cent MM in block	58.37	25.44	16.19	....	100.00
Per cent MM in column	....	....	....	....	2.27
CALCITE:					
Weight in grams	.586	.167	.134	....	.887
Per cent section block	1.40	0.40	0.33	....	2.12
Per cent MM in block	39.86	11.36	9.12	....	60.34
Per cent calcite in column	....	....	....	....	6.03
PYRITE:					
Weight in grams	.006	.014	.015	....	.035
Per cent section block	0.01	0.03	0.04	....	0.08
Per cent MM in block	0.41	0.95	1.02	....	2.38
Per cent pyrite in column	....	....	....	....	0.48
DETRITAL CLAY:					
Weight in grams	.032	.030	.015	....	.077
Per cent section block	0.08	0.07	0.04	....	0.18
Per cent MM in block	2.18	2.04	1.02	....	5.24
Per cent clay in column	....	....	....	....	0.28
KAOLINITE:					
Weight in grams	.234	.163	.074	....	.471
Per cent section block	0.56	0.39	0.17	....	1.13
Per cent MM in block	15.91	11.09	5.03	....	32.04
Per cent kaolinite in column	....	....	....	....	3.08

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-1B			
Height in mm	....	....	....	....	117.0
Per cent height of column	....	....	....	....	4.31
Weight in grams	28.042	15.953	15.375	....	59.370
Per cent weight of column	....	....	....	....	3.58
MINERAL MATTER:					
Weight in grams	2.723	1.240	.669	.013	4.645
Per cent section block	4.59	2.09	1.13	0.02	7.82
Per cent MM in block	58.63	26.69	14.40	0.28	100.00
Per cent MM in column	....	....	....	....	7.16
CALCITE:					
Weight in grams	1.538	.739	.461	....	2.738
Per cent section block	2.59	1.24	0.78	....	4.61
Per cent MM in block	33.11	15.91	9.92	....	58.94
Per cent calcite in column	....	....	....	....	18.63
PYRITE:					
Weight in grams	.006	.013	.008	....	.027
Per cent section block	0.01	0.02	0.01	....	0.04
Per cent MM in block	0.13	0.28	0.17	....	0.58
Per cent pyrite in column	....	....	....	....	0.37
DETRITAL CLAY					
Weight in grams	....	....	....	....	....
Per cent section block	....	....	....	....	....
Per cent MM in block	....	....	....	....	....
Per cent clay in column	....	....	....	....	....
KAOLINITE:					
Weight in grams	1.179	.488	.213	....	1.880
Per cent section block	1.99	0.82	0.36	....	3.17
Per cent MM in block	25.38	10.51	4.59	....	40.48
Per cent kaolinite in column	....	....	....	....	12.28

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-2-(1-5)			
Height in mm.	....	....	....	....	100.0
Per cent height of column.	....	....	....	....	4.05
Weight in grams	28.374	20.483	13.850	....	62.707
Per cent weight of column	....	....	....	....	3.84
MINERAL MATTER:					
Weight in grams	3.333	1.871	.532	.115	5.851
Per cent section block	5.31	2.98	0.85	0.18	9.33
Per cent MM in block	56.96	31.98	9.09	1.97	100.00
Per cent MM in column.	....	....	....	....	9.02
CALCITE:					
Weight in grams	1.750	1.126	.429	....	3.305
Per cent section block	2.79	1.79	0.68	....	5.27
Per cent MM in block	29.91	19.24	7.33	....	56.49
Per cent calcite in column.	....	....	....	....	22.49
PYRITE:					
Weight in grams	.058	.031	.0105	....	.099
Per cent section block	0.09	0.05	0.02	....	0.16
Per cent MM in block	0.99	0.53	0.18	....	1.70
Per cent pyrite in column.	....	....	....	....	1.35
DETRITAL CLAY:					
Weight in grams	.684	.216	.051	....	.951
Per cent section block	1.09	0.34	0.08	....	1.52
Per cent MM in block	11.69	3.69	0.87	....	16.25
Per cent clay in column	....	....	....	....	3.46
KAOLINITE:					
Weight in grams	.841	.498	.1565	....	1.495
Per cent section block	1.34	0.80	0.25	....	2.38
Per cent MM in block	14.37	8.51	2.68	....	25.56
Per cent kaolinite in column	....	....	....	....	9.77

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-BB			
Height in mm	....	....	....	....	40.0
Per cent height of column	....	....	....	....	1.47
Weight in grams	....	....	....	....	24.295
Per cent weight of column	....	....	....	....	1.46
MINERAL MATTER:					
Weight in grams	5.700	3.710	6.641	....	16.051
Per cent section block	23.46	15.27	27.33	....	66.07
Per cent MM in block	35.51	23.11	41.38	....	100.00
Per cent MM in column	....	....	....	....	24.76
CALCITE:					
Weight in grams	.162	.144	.406	....	.712
Per cent section block	0.67	0.59	1.67	....	2.93
Per cent MM in block	1.01	0.90	2.53	....	4.44
Per cent calcite in column	....	....	....	....	4.84
PYRITE:					
Weight in grams	.002	.002	.002	....	.006
Per cent section block	0.01	0.01	0.01	....	0.02
Per cent MM in block	0.01	0.01	0.01	....	0.04
Per cent pyrite in column	....	....	....	....	0.08
DETRITAL CLAY:					
Weight in grams	5.536	3.564	6.233	....	15.333
Per cent section block	22.79	14.67	25.65	....	63.11
Per cent MM in block	34.49	22.20	38.83	....	95.53
Per cent clay in column	....	....	....	....	55.80
KAOLINITE:					
Weight in grams	....	....	....	....	....
Per cent section block	....	....	....	....	....
Per cent MM in block	....	....	....	....	....
Per cent kaolinite in column	....	....	....	....	....

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-3A-(3-7)			
Height in mm	....	....	....	....	100.5
Per cent height of column	....	....	....	....	3.70
Weight in grams	....	....	....	....	46.369
Per cent weight of column	....	....	....	....	2.79
MINERAL MATTER:					
Weight in grams	.488	.374	.210	....	1.072
Per cent section block	1.05	0.81	0.45	....	2.31
Per cent MM in block	45.52	34.89	19.59	....	100.00
Per cent MM in column	....	....	....	....	1.65
CALCITE:					
Weight in grams	.042	.038	.065	....	.145
Per cent section block	0.09	0.08	0.14	....	0.31
Per cent MM in block	3.92	3.54	6.06	....	13.53
Per cent calcite in column	....	....	....	....	0.99
PYRITE:					
Weight in grams	.006	.006	.007	....	.019
Per cent section block	0.01	0.01	0.01	....	0.04
Per cent MM in block	0.56	0.56	0.65	....	1.77
Per cent pyrite in column	....	....	....	....	0.26
DETRITAL CLAY:					
Weight in grams	.159	.158	.080	....	.397
Per cent section block	0.34	0.34	0.17	....	0.86
Per cent MM in block	14.83	14.74	7.46	....	37.03
Per cent clay in column	....	....	....	....	1.44
KAOLINITE:					
Weight in grams	.281	.172	.058	....	.511
Per cent section block	0.61	0.37	0.13	....	1.10
Per cent MM in block	26.21	16.04	5.14	....	47.67
Per cent kaolinite in column	....	....	....	....	3.34

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-3B-(1-6)			
Height in mm	....	....	....	....	126.5
Per cent height of column	....	....	....	....	4.66
Weight in grams	....	....	....	....	59.361
Per cent weight of column	....	....	....	....	3.58
MINERAL MATTER:					
Weight in grams	.341	.251	.186	....	.778
Per cent section block	0.57	0.42	0.31	....	1.31
Per cent MM in block	43.83	32.26	23.91	....	100.00
Per cent MM in column	....	....	....	....	1.20
CALCITE:					
Weight in grams	.012	.020	.040	....	.072
Per cent section block	0.02	0.03	0.07	....	0.12
Per cent MM in block	1.54	2.57	5.14	....	9.25
Per cent calcite in column	....	....	....	....	0.49
PYRITE:					
Weight in grams	.013	.0105	.0048	....	.0283
Per cent section block	0.02	0.02	0.01	....	0.05
Per cent MM in block	1.67	1.35	0.62	....	3.64
Per cent pyrite in column	....	....	....	....	0.38
DETRITAL CLAY:					
Weight in grams	.126	.087	.056	....	.269
Per cent section block	0.21	0.15	0.09	....	0.45
Per cent MM in block	16.19	11.18	7.20	....	34.58
Per cent clay in column	....	....	....	....	0.98
KAOLINITE:					
Weight in grams	.190	.1335	.0852	....	.4087
Per cent section block	0.32	0.22	0.15	....	0.69
Per cent MM in block	24.43	17.16	10.95	....	52.53
Per cent kaolinite in column	....	....	....	....	2.67

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-4A-(1-	4)		
Height in mm	....	....	....	....	93.0
Per cent height of column	....	....	....	....	3.43
Weight in grams	....	....	....	....	54.735
Per cent weight of column	....	....	....	....	3.30
MINERAL MATTER:					
Weight in grams	.456	.282	.202	....	.940
Per cent section block	0.83	0.51	0.37	....	1.72
Per cent MM in block	48.51	30.00	21.49	....	100.00
Per cent MM in column	....	....	....	....	1.45
CALCITE:					
Weight in grams	.002	.002	.016	....	.020
Per cent section block	0.004	0.004	0.03	....	0.04
Per cent MM in block	0.21	0.21	1.70	....	2.13
Per cent calcite in column	....	....	....	....	0.14
PYRITE:					
Weight in grams	.0045	.0055	.0025	....	.0125
Per cent section block	0.01	0.01	0.005	....	0.03
Per cent MM in block	0.48	0.58	0.27	....	1.33
Per cent pyrite in column	....	....	....	....	0.17
DETRITAL CLAY:					
Weight in grams	.311	.159	.086	....	.556
Per cent section block	0.57	0.29	0.16	....	1.02
Per cent MM in block	33.09	16.91	9.15	....	59.15
Per cent clay in column	....	....	....	....	2.02
KAOLINITE:					
Weight in grams	.1385	.1155	.0975	....	.3815
Per cent section block	0.25	0.21	0.17	....	0.64
Per cent MM in block	14.73	12.29	10.37	....	37.39
Per cent kaolinite in column	....	....	....	....	2.49

	48 x 100	190 x 200	200 x 0	200 x 0	Total
		24-4B-(1-5)			
Height in mm	....	....	....	....	99.0
Per cent height of column	....	....	....	....	3.65
Weight in grams	23.821	19.186	16.495	....	59.502
Per cent weight of column	....	....	....	....	3.58
MINERAL MATTER:					
Weight in grams	.917	.764	.139	.113	1.933
Per cent section block	1.54	1.28	0.23	0.19	3.25
Per cent MM in block	47.44	39.52	7.19	5.85	100.00
Per cent MM in column	....	....	....	....	2.98
CALCITE:					
Weight in grams	.052	.041	.057	....	.150
Per cent section block	0.09	0.07	0.10	....	0.25
Per cent MM in block	2.69	2.12	2.95	....	7.76
Per cent calcite in column	....	....	....	....	1.02
PYRITE:					
Weight in grams	.046	.078	.049	....	.173
Per cent section block	0.08	0.13	0.08	....	0.29
Per cent MM in block	2.38	4.03	2.53	....	8.95
Per cent pyrite in column	....	....	....	....	2.35
DETRITAL CLAY:					
Weight in grams	.469	.392	.096	....	.957
Per cent section block	0.79	0.66	0.16	....	1.61
Per cent MM in block	24.26	20.28	4.97	....	49.51
Per cent clay in column	....	....	....	....	3.48
KAOLINITE:					
Weight in grams	.350	.253	.050	....	.653
Per cent section block	0.59	0.42	0.08	....	1.10
Per cent MM in block	18.11	13.09	2.58	....	33.78
Per cent kaolinite in column	....	....	....	....	4.26

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-4C-(1-5)			
Height in mm.	....	....	....	....	104.0
Per cent height of column.	....	....	....	....	3.83
Weight in grams.	24.122	17.855	13.305	....	55.282
Per cent weight of column.	....	....	....	....	3.33
MINERAL MATTER:					
Weight in grams.	1.458	.714	.141	.142	2.455
Per cent section block.	2.64	1.29	0.25	0.26	4.44
Per cent MM in block.	59.39	29.08	5.74	5.79	100.00
Per cent MM in column.	....	....	....	....	3.79
CALCITE:					
Weight in grams.	.036	.032	.044	....	.112
Per cent section block.	0.06	0.06	0.08	....	0.20
Per cent MM in block.	1.47	1.30	1.79	....	4.56
Per cent calcite in column.	....	....	....	....	0.76
PYRITE:					
Weight in grams.	.0145	.0295	.011	....	0.55
Per cent section block.	0.03	0.05	0.02	....	0.10
Per cent MM in block.	0.59	1.20	0.45	....	2.24
Per cent pyrite in column.	....	....	....	....	0.75
DETRITAL CLAY:					
Weight in grams.	1.004	.382	.151	....	1.537
Per cent section block.	1.82	0.69	0.27	....	2.78
Per cent MM in block.	40.90	15.56	6.15	....	62.61
Per cent clay in column.	....	....	....	....	5.59
KAOLINITE:					
Weight in grams.	.4035	.2705	.077	....	.751
Per cent section block.	0.73	0.49	0.14	....	1.36
Per cent MM in block	16.43	11.02	3.14	....	30.59
Per cent kaolinite in column	....	....	....	....	4.90

	48 x 100	190 x 200	200 x 0	200 x 0	Total
		24-4D-(1	-6)		
Height in mm	....	....	....	....	111.5
Per cent height of column	....	....	....	....	4.11
Weight in grams	26.386	24.906	16.852	....	68.144
Per cent weight of column	....	....	....	....	4.10
MINERAL MATTER:					
Weight in grams	1.052	.692	.257	.122	2.123
Per cent section block	1.54	1.01	0.38	0.18	3.11
Per cent MM in block	49.55	32.59	12.10	5.76	100.00
Per cent MM in column	....	....	....	....	3.27
CALCITE:					
Weight in grams	.032	.034	.056	....	.122
Per cent section block	0.05	0.05	0.08	....	0.18
Per cent MM in block	1.51	1.60	2.64	....	5.74
Per cent calcite in column	....	....	....	....	0.83
PYRITE:					
Weight in grams	.102	.171	.098	....	.371
Per cent section block	0.15	0.25	0.14	....	0.54
Per cent MM in block	4.80	8.05	4.62	....	17.47
Per cent pyrite in column	....	....	....	....	5.05
DETRITAL CLAY:					
Weight in grams	.622	.255	.123	....	1.000
Per cent section block	0.91	0.37	0.18	....	1.47
Per cent MM in block	29.30	12.01	5.79	....	47.10
Per cent clay in column	....	....	....	....	3.64
KAOLINITE:					
Weight in grams	.296	.232	.102	....	.630
Per cent section block	0.44	0.34	0.15	....	0.92
Per cent MM in block	13.94	10.93	4.81	....	29.68
Per cent kaolinite in column	....	....	....	....	4.11

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-5			
Height in mm	....	....	....	....	142.5
Per cent height of column	....	....	....	....	5.25
Weight in grams	33.697	21.827	12.555	....	68.079
Per cent weight of column	....	....	....	....	4.10
MINERAL MATTER:					
Weight in grams	.341	.193	.072	.011	.617
Per cent section block	0.50	0.28	0.11	0.02	0.91
Per cent MM in block	55.27	31.28	11.67	1.78	100.00
Per cent MM in column	....	....	....	....	0.95
CALCITE:					
Weight in grams	.003	.005	.025	....	.033
Per cent section block	0.005	0.01	0.04	....	0.05
Per cent MM in block	0.49	0.81	4.05	....	5.35
Per cent calcite in column	....	....	....	....	0.22
PYRITE:					
Weight in grams	.013	.023	.020	....	.056
Per cent section block	0.02	0.03	0.03	....	0.08
Per cent MM in block	2.11	3.73	3.24	....	9.08
Per cent pyrite in column	....	....	....	....	0.76
DETRITAL CLAY:					
Weight in column	.049	.025	.006	....	.080
Per cent section block	0.07	0.04	0.01	....	0.12
Per cent MM in block	7.94	4.05	0.97	....	12.97
Per cent clay in column	....	....	....	....	0.29
KAOLINITE:					
Weight in grams	.276	.140	.032	....	.448
Per cent section block	0.41	0.20	0.05	....	0.66
Per cent MM in block	44.73	22.69	5.19	....	72.60
Per cent kaolinite in column	....	....	....	....	2.92

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-6-(1-2)			
Height in mm	....	... .	....	....	102.5
Per cent height of column	....	....	....	....	3.78
Weight in grams	40.027	17.470	10.664	....	68.161
Per cent weight of column	....	....	....	....	4.11
MINERAL MATTER:					
Weight in grams	.459	.188	.053	.006	.706
Per cent section block	0.67	0.28	0.08	0.01	1.04
Per cent MM in block	65.01	26.63	7.51	0.85	100.00
Per cent MM in column	....	....	....	....	1.09
CALCITE:					
Weight in grams	.001	.006	.018	....	.025
Per cent section block	0.001	0.01	0.03	....	0.04
Per cent MM in block	0.14	0.85	2.55	....	3.54
Per cent calcite in column	....	....	....	....	0.17
PYRITE:					
Weight in grams	.007	.016	.014	....	.037
Per cent section block	0.01	0.02	0.02	....	0.05
Per cent MM in block	0.99	2.27	1.98	....	5.24
Per cent pyrite in column	....	....	....	....	0.50
DETRITAL CLAY:					
Weight in grams	.087	.043	.006	....	.136
Per cent section block	0.13	0.06	0.001	....	0.20
Per cent MM in block	12.32	6.09	0.85	....	19.26
Per cent clay in column	....	....	....	....	0.57
KAOLINITE:					
Weight in grams	.364	.123	.021	....	.508
Per cent section block	0.53	0.18	0.04	....	0.74
Per cent MM in block	51.56	17.42	2.97	....	71.96
Per cent kaolinite in column	....	....	....	....	3.32

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-7A-(1	**-4)**		
Height in mm	....	....	....	....	97.0
Per cent height of column	....	....	....	....	3.57
Weight in grams	23.006	21.372	11.063	....	55.441
Per cent weight of column	....	....	....	....	3.34
MINERAL MATTER:					
Weight in grams	.638	.478	.193	.154	1.463
Per cent section block	1.15	0.86	0.35	0.28	2.64
Per cent MM in block	43.61	32.67	13.19	10.53	100.00
Per cent MM in column	....	....	....	....	2.26
CALCITE:					
Weight in grams	.023	.023	.066	....	.112
Per cent section block	0.04	0.04	0.12	....	0.20
Per cent MM in block	1.57	1.57	4.51	....	7.65
Per cent calcite in column	....	....	....	....	0.76
PYRITE:					
Weight in grams	.064	.075	.095	....	.234
Per cent section block	0.11	0.13	0.17	....	0.42
Per cent MM in block	4.37	5.13	6.49	....	15.99
Per cent pyrite in column	....	....	....	....	3.18
DETRITAL CLAY:					
Weight in grams	.212	.117	.069	....	.398
Per cent section block	0.38	0.21	0.12	....	0.72
Per cent MM in block	14.49	8.00	4.72	....	27.20
Per cent clay in column	....	....	....	....	1.45
KAOLINITE:					
Weight in grams	.339	.263	.117	....	.719
Per cent section block	0.61	0.47	0.21	....	1.29
Per cent MM in block	23.17	17.97	7.99	....	49.15
Per cent kaolinite in column	....	....	....	....	4.69

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-7B-(1-5)			
Height in mm					155.0
Per cent height of column					5.71
Weight in grams	38.315	30.426	16.275		85.016
Per cent weight of column					5.12
MINERAL MATTER:					
Weight in grams	1.595	1.254	.507	.106	3.462
Per cent section block	1.88	1.47	0.60	0.12	4.07
Per cent MM in block	46.07	36.22	14.64	3.07	100.0
Per cent MM in column					5.34
CALCITE:					
Weight in grams	.075	.081	.097		.253
Per cent section block	0.09	0.09	0.11		0.30
Per cent MM in block	2.17	2.34	2.80		7.31
Per cent calcite in column					1.72
PYRITE:					
Weight in grams	.3045	.422	.2605		.987
Per cent section block	0.36	0.50	0.31		1.16
Per cent MM in block	8.79	12.19	7.52		28.51
Per cent pyrite in column					13.43
DETRITAL CLAY:					
Weight in grams	1.052	.621	.204		1.877
Per cent section block	1.24	0.73	0.24		2.21
Per cent MM in block	30.39	17.94	5.89		54.22
Per cent clay in column					6.83
KAOLINITE:					
Weight in grams	.1635	.130	.0515		.345
Per cent section block	0.19	0.15	0.06		0.41
Per cent MM in block	4.72	3.75	1.49		9.96
Per cent kaolinite in column					2.25

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-7C-(1-5)			
Height in mm	....	....	....	....	163.0
Per cent height of column	....	....	....	....	6.00
Weight in grams	36.025	20.279	13.096	....	69.400
Per cent weight of column	....	....	....	....	4.18
MINERAL MATTER:					
Weight in grams	.279	.136	.053	.0145	.4825
Per cent section block	0.40	0.20	0.08	0.02	0.69
Per cent MM in block	57.82	28.19	10.98	3.01	100.00
Per cent MM in column	....	....	....	....	0.74
CALCITE:					
Weight in grams	.003	.003	.0145	....	.0205
Per cent section block	0.004	0.004	0.02	....	0.03
Per cent MM in block	0.62	0.62	3.00	....	4.25
Per cent calcite in column	....	....	....	....	0.14
PYRITE:					
Weight in grams	.001	.003	.008	....	.012
Per cent section block	0.001	0.004	0.01	....	0.02
Per cent MM in block	0.21	0.62	1.66	....	2.49
Per cent pyrite in column	....	....	....	....	0.16
DETRITAL CLAY:					
Weight in grams	.005	.001	.0005	....	.0065
Per cent section block	0.01	0.001	0.001	....	0.01
Per cent MM in block	1.04	0.21	0.10	....	1.35
Per cent clay in column	....	....	....	....	0.02
KAOLINITE:					
Weight in grams	.270	.129	.0445	....	.4435
Per cent section block	0.39	0.19	0.06	....	0.64
Per cent MM in block	55.95	26.73	9.23	....	91.91
Per cent kaolinite in column	....	....	....	....	2.90

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-8A			
Height in mm	....	....	....	....	59.0
Per cent height of column	....	....	....	....	2.17
Weight in grams	19.289	8.420	5.784	....	33.493
Per cent weight of column	....	....	....	....	2.02
MINERAL MATTER:					
Weight in grams	.092	.050	.017	.003	.162
Per cent section block	0.27	0.15	0.05	0.01	0.48
Per cent MM in block	56.80	30.86	10.49	1.85	100.00
Per cent MM in column	....	....	....	....	0.25
CALCITE:					
Weight in grams	.017	.009	.009	....	.035
Per cent section block	0.05	0.03	0.03	....	0.10
Per cent MM in block	10.49	5.56	5.56	....	21.60
Per cent calcite in column	....	....	....	....	0.24
PYRITE:					
Weight in grams	tr	tr	tr	....	.001
Per cent section block	0.00	0.00	0.00	....	0.003
Per cent MM in block	0.00	0.00	0.00	....	0.62
Per cent pyrite in column	....	....	....	....	0.01
DETRITAL CLAY:					
Weight in grams	....	....	....	....	....
Per cent section block	....	....	....	....	....
Per cent MM in block	....	....	....	....	....
Per cent clay in column	....	....	....	....	....
KAOLINITE:					
Weight in grams	.075	.041	.011	....	.126
Per cent section block	0.22	0.12	0.03	....	0.38
Per cent MM in block	46.30	25.31	6.79	....	77.78
Per cent kaolinite in column	....	....	....	....	0.82

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-8B			
Height in mm	....	....	....	....	146.0
Per cent height of column	....	....	....	....	5.38
Weight in grams	41.762	31.839	25.286	....	98.887
Per cent weight of column	....	....	....	....	6.18
MINERAL MATTER:					
Weight in grams	.508	.253	.137	.028	.926
Per cent section block	0.51	0.26	0.14	0.03	0.94
Per cent MM in block	54.87	27.32	14.79	3.02	100.00
Per cent MM in column	....	....	....	....	1.43
CALCITE:					
Weight in grams	.000	.003	.029	....	.032
Per cent section block	0.00	0.003	0.03	....	0.03
Per cent MM in block	0.00	0.32	3.13	....	3.45
Per cent calcite in column	....	....	....	....	0.22
PYRITE:					
Weight in grams	.0005	.003	.009	....	.0125
Per cent section block	0.001	0.003	0.01	....	0.01
Per cent MM in block	0.05	0.32	0.97	....	1.35
Per cent pyrite in column	....	....	....	....	0.17
DETRITAL CLAY:					
Weight in grams	....	....	....	....	....
Per cent section block	....	....	....	....	....
Per cent MM in block	....	....	....	....	....
Per cent clay in column	....	....	....	....	....
KAOLINITE:					
Weight in grams	.5075	.247	.127	....	.8815
Per cent section block	0.51	0.25	0.13	....	0.89
Per cent MM in block	54.81	26.67	13.71	....	95.20
Per cent kaolinite in column	....	....	....	....	5.76

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-9-(1-5)			
Height in mm	....	....	....	....	119.5
Per cent height of column	....	....	....	....	4.40
Weight in grams	31.229	18.226	15.412	....	64.867
Per cent weight of column	....	....	....	....	3.91
MINERAL MATTER:					
Weight in grams	.441	.271	.169	.018	.899
Per cent section block	0.68	0.42	0.26	0.03	1.39
Per cent MM in block	49.05	30.14	18.80	2.01	100.00
Per cent MM in column	....	....	....	....	1.39
CALCITE:					
Weight in grams	.035	.021	.049	....	.105
Per cent section block	0.05	0.03	0.07	....	0.16
Per cent MM in block	3.89	2.34	5.45	....	11.68
Per cent calcite in column	....	....	....	....	0.71
PYRITE:					
Weight in grams	.0925	.107	.096	....	.2955
Per cent section block	0.14	0.16	0.15	....	0.45
Per cenr MM in block	10.29	11.90	10.68	....	32.87
Per cent pyrite in column	....	....	....	....	4.02
DETRITAL CLAY:					
Weight in grams	.001	....	....	....	.001
Per cent section block	0.001	....	....	....	0.001
Per cent MM in block	0.11	....	....	....	0.11
Per cent clay in column	....	....	....	....	0.004
KAOLINITE:					
Weight in grams	.3125	.143	.042	....	.4975
Per cent section block	0.48	0.22	0.06	....	0.77
Per cent MM in block	34.76	15.91	4.67	....	55.34
Per cent kaolinite in column	....	....	....	....	3.25

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-10-(1-3)			
Height in mm	....	....	....	....	91.0
Per cent height of column	....	....	....	....	3.35
Weight in grams	22.851	13.790	9.793	....	46.434
Per cent weight of column	....	....	....	....	2.80
MINERAL MATTER:					
Weight in grams	.087	.075	.019	.014	.195
Per cent section block	0.19	0.16	0.04	0.03	0.42
Per cent MM in block	44.61	38.46	9.74	7.19	100.00
Per cent MM in column	....	....	....	....	0.30
CALCITE:					
Weight in grams	.002	.007	.016	....	.025
Per cent section block	0.004	0.015	0.03	....	0.05
Per cent MM in block	1.03	3.59	8.20	....	12.82
Per cent calcite in column	....	....	....	....	0.17
PYRITE:					
Weight in grams	.018	.015	.003	....	.036
Per cent section block	0.04	0.03	0.006	....	0.08
Per cent MM in block	9.23	7.69	1.54	....	18.46
Per cent pyrite in column	....	....	....	....	0.49
DETRITAL CLAY:					
Weight in grams	.016	.009	.003	....	.028
Per cent section block	0.03	0.02	0.006	....	0.06
Per cent MM in block	8.20	4.62	1.54	....	14.36
Per cent clay in column	....	....	....	....	0.10
KAOLINITE:					
Weight in grams	.051	.044	.011	....	.106
Per cent section block	0.11	0.09	0.02	....	0.23
Per cent MM in block	26.16	22.56	5.64	....	54.36
Per cent kaolinite in column	....	....	....	....	0.69

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-11A-(1-4)			
Height in mm	....	....	....	....	88.0
Per cent height of column	....	....	....	....	3.24
Weight of grams	26.500	15.287	9.139	....	50.926
Per cent weight of column	....	....	....	....	3.07
MINERAL MATTER:					
Weight in grams	.153	.100	.027	.002	.282
Per cent section block	0.30	0.20	0.05	0.004	0.55
Per cent MM in block	54.25	35.46	9.57	0.72	100.0
Per cent MM in column	....	....	....	....	0.43
CALCITE:					
Weight in grams	.005	.015	.014	....	.034
Per cent section block	0.01	0.03	0.03	....	0.07
Per cent MM in block	1.77	5.32	4.96	....	12.06
Per cent calcite in column	....	....	....	....	0.23
PYRITE:					
Weight in grams	.002	.007	tr	....	.009
Per cent section block	0.004	0.01	0.00	....	0.02
Per cent MM in block	0.72	2.48	0.00	....	3.19
Per cent pyrite in column	....	....	....	....	0.12
DETRITAL CLAY:					
Weight in grams	.019	.009	.002	....	.030
Per cent section block	0.04	0.02	0.004	....	0.06
Per cent MM in block	6.74	3.19	0.72	....	10.64
Per cent clay in column	....	....	....	....	0.11
KAOLINITE:					
Weight in grams	.127	.069	.013	....	.209
Per cent section block	0.25	0.13	0.03	....	0.41
Per cent MM in block	45.03	24.47	4.60	....	74.11
Per cent kaolinite in column	....	....	....	....	1.36

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-11B			
Height in mm.	....	....	....	....	112.5
Per cent height of column.	....	....	....	....	4.14
Weight in grams.	33.150	22.876	16.517	....	72.543
Per cent weight of column.	....	....	....	....	4.37
MINERAL MATTER:					
Weight in grams.	2.031	1.162	.365	.001	3.559
Per cent section block.	2.80	1.60	0.50	0.001	4.91
Per cent MM in block.	57.06	32.65	10.26	0.03	100.00
Per cent MM in column.	....	....	....	....	5.49
CALCITE:					
Weight in grams.	.000	.002	.036	....	.038
Per cent section block.	0.00	0.003	0.05	....	0.053
Per cent MM in block.	0.00	0.06	1.01	....	1.07
Per cent calcite in column.	....	....	....	....	0.26
PYRITE:					
Weight in grams.	.008	.011	.004	....	.023
Per cent section block.	0.01	0.015	0.005	....	0.03
Per cent MM in block.	0.22	0.31	0.11	....	0.65
Per cent pyrite in column.	....	....	....	....	0.31
DETRITAL CLAY:					
Weight in grams.	1.618	.919	.293	....	2.830
Per cent section block.	2.23	1.27	0.40	....	3.89
Per cent MM in block.	45.46	25.82	8.23	....	79.23
Per cent clay in column.	....	....	....	....	10.30
KAOLINITE:					
Weight in grams.	.405	.230	.033	....	.668
Per cent section block.	0.56	0.31	0.05	....	0.93
Per cent MM in block.	11.38	6.46	0.93	....	18.77
Per cent kaolinite in column	....	....	....	....	4.36

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-R1			
Height in mm	....	....	....	....	108.0
Per cent height of column	....	....	....	....	3.98
Weight in grams	45.988	50.549	58.765	....	155.302
Per cent weight of column	....	....	....	....	9.36
MINERAL MATTER:					
Weight in grams	2.617	3.145	1.219	.155	7.136
Per cent section block	1.68	2.02	0.78	0.10	4.59
Per cent MM in block	36.68	44.07	17.08	2.17	100.00
Per cent MM in column	....	....	....	....	11.01
CALCITE:					
Weight in grams	.567	.738	.162	....	1.467
Per cent section block	0.36	0.47	0.10	....	0.94
Per cent MM in block	7.95	10.34	2.27	....	20.56
Per cent calcite in column	....	....	....	....	9.98
PYRITE:					
Weight in grams	1.596	1.952	1.001	....	4.549
Per cent section block	1.03	1.26	0.64	....	2.93
Per cent MM in block	22.36	27.35	14.03	....	63.75
Per cent pyrite in column	....	....	....	....	61.89
DETRITAL CLAY:					
Weight in grams	.272	.318	.169	....	.759
Per cent section block	0.17	0.20	0.11	....	0.48
Per cent MM in block	3.81	4.46	2.37	....	10.64
Per cent clay in column	....	....	....	....	2.76
KAOLINITE:					
Weight in grams	.182	.137	.042	....	.361
Per cent section block	0.12	0.09	0.03	....	0.24
Per cent MM in block	2.55	1.92	0.59	....	5.05
Per cent kaolinite in column	....	....	....	....	2.36

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-R2			
Height in mm	....	....	....	....	90.5
Per cent height of column	....	....	....	....	3.33
Weight in grams	30.761	21.251	18.517	....	70.529
Per cent weight of column	....	....	....	....	4.25
MINERAL MATTER:					
Weight in grams	.366	.228	.067	.002	.663
Per cent section block	0.52	0.32	0.09	0.005	0.94
Per cent MM in block	55.20	34.39	10.11	0.30	100.00
Per cent MM in column	....	....	....	....	1.02
CALCITE:					
Weight in grams	.026	.024	.012	....	.062
Per cent section block	0.04	0.03	0.02	....	0.09
Per cent MM in block	3.92	3.62	1.81	....	9.35
Per cent calcite in column	....	....	....	....	0.42
PYRITE:					
Weight in grams	.121	.080	.030	....	.231
Per cent section block	0.17	0.11	0.04	....	0.33
Per cent MM in block	18.25	12.07	4.52	....	34.84
Per cent pyrite in column	....	....	....	....	3.14
DETRITAL CLAY:					
Weight in grams	.022	.012	.005	....	.039
Per cent section block	0.03	0.02	0.01	....	0.06
Per cent MM in block	3.32	1.81	0.75	....	5.88
Per cent clay in column	....	....	....	....	0.14
KAOLINITE:					
Weight in grams	.197	.112	.022	....	.331
Per cent section block	0.28	0.16	0.03	....	0.46
Per cent MM in block	29.71	16.89	3.32	....	49.93
Per cent kaolinite in column	....	....	....	....	2.16

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		24-R3			
Height in mm	....	....	....	....	59.0
Per cent height of column	....	....	....	....	2.17
Weight in grams	8.143	14.173	16.419	....	38.735
Per cent weight of column	....	....	....	....	2.33
MINERAL MATTER:					
Weight in grams	.237	.229	.071	.001	.538
Per cent section block	0.61	0.59	0.18	0.02	1.39
Per cent MM in block	44.05	42.56	13.20	0.19	100.00
Per cent MM in column	....	....	....	....	0.83
CALCITE:					
Weight in grams	.065	.053	.026	....	.144
Per cent section block	0.17	0.14	0.07	....	0.37
Per cent MM in block	12.08	9.85	4.83	....	26.77
Per cent calcite in column	....	....	....	....	0.98
PYRITE:					
Weight in grams	.003	.003	.003	....	.009
Per cent section block	0.01	0.01	0.01	....	0.02
Per cent MM in block	0.56	0.56	0.56	....	1.67
Per cent pyrite in column	....	....	....	....	0.12
DETRITAL CLAY:					
Weight in grams	0.85	.104	.026	....	.215
Per cent section block	0.22	0.27	0.07	....	0.56
Per cent MM in block	15.80	19.33	4.83	....	39.96
Per cent clay in column	....	....	....	....	0.78
KAOLINITE:					
Weight in grams	.084	.069	.017	....	.170
Per cent section block	0.22	0.18	0.04	....	0.43
Per cent MM in block	15.61	12.83	3.16	....	31.60
Per cent kaolinite in column	....	....	....	....	1.11

	48 x 100	100 x 200	200 x 0	200 x 0	Total
		Column 24			
Height in mm	....	....	....	....	2714.5
Per cent height of column	....	....	....	....	100.00
Weight in grams	... ...	....	....	......	1659.890
Per cent weight of column	....	....	....	....	100.00
MINERAL MATTER:					
Weight in grams	32.013	19.603	12.199	1.0225	64.8375
Per cent section block	1.93	1.18	0.73	0.06	3.91
Per cent MM in block	49.37	30.23	18.81	1.59	100.00
Per cent MM in column	....	....	....	....	100.00
CALCITE:					
Weight in grams	7.987	4.418	2.292	....	14.697
Per cent section block	0.48	0.27	0.14	....	0.88
Per cent MM in block	12.32	6.81	3.53	....	22.67
Per cent calcite in column	....	....	....	....	100.00
PYRITE:					
Weight in grams	2.5075	3.0885	1.7533	....	7.3503
Per cent section block	0.15	0.19	0.10	....	0.44
Per cent MM in block	3.87	4.76	2.86	....	11.34
Per cent pyrite in column	....	....	....	....	100.00
DETRITAL CLAY:					
Weight in grams	12.381	7.421	7.6745	....	27.4765
Per cent section block	0.75	0.45	0.46	....	1.65
Per cent MM in block	19.09	11.44	11.84	....	42.37
Per cent clay in column	....	....	....	....	100.00
KAOLINITE:					
Weight in grams	9.1375	4.6755	1.5007	....	15.3137
Per cent section block	0.55	0.28	0.09	....	0.93
Per cent MM in block	14.10	7.22	2.31	....	23.62
Per cent kaolinite in column	....	....	....	....	100.00